



Phosphorus TMDL for Lac Courte Oreilles

Sawyer County, Wisconsin



Draft

July 16, 2014

Blank Page



Phosphorus TMDL for Lac Courte Oreilles Sawyer County, Wisconsin

**DRAFT
July 16, 2014**

**Prepared by:
LimnoTech**

Blank page



TABLE OF CONTENTS

1 Introduction.....	1
2 Problem Statement.....	3
Water Quality Targets	3
Monitoring Background	5
3 Load Development	9
Major Tributary Loads	9
Other Direct Drainage Area Loads.....	11
Cranberry Bog Loads.....	13
Atmospheric Loads.....	13
4 Water Quality Model Development.....	15
Model Selection	15
Model Inputs	15
Model Options.....	15
Global Variables.....	16
Segmentation	16
Dispersion Coefficients.....	17
Phosphorus Loads.....	17
Model Calibration.....	18
5 TMDL Development.....	21
Linkage Analysis.....	21
Water Quality Goals	21
Loading Capacity	22
Wasteload Allocation.....	23
Load Allocation.....	23
Margin of Safety.....	24
Seasonal Variation.....	24
Reasonable Assurance.....	25
Public Participation	26
6 Implementation	27
LCO Shoreline/Riparian Landowners	27
In-Lake Management	28
Agriculture	28
Forest Management Practices.....	29
Small Communities, Rural Residential, and New Development.....	30
Cranberry Bog Discharges.....	31
Monitoring and Adaptive Management.....	31
7 References	33



LIST OF FIGURES

Figure 1. Location of Lac Courte Oreilles.....	2
Figure 2. Seasonal mean total phosphorus (June 1-Sept 15) in major bays and basins of LCO (2002-2013). Errors bars indicate ± 1 SD.	5
Figure 3. Seasonal mean chlorophyll <i>a</i> (July 15- Sept 15) in major basins and bays of LCO (2002-2013). Errors bars indicate ± 1 SD.	6
Figure 4. Seasonal mean secchi depth (July 15- Sept 15) in major basins and bays of LCO (2002-2013). Errors bars indicate ± 1 SD.	6
Figure 5. Subwatershed delineations.....	10
Figure 6. Watershed land use designations.....	12
Figure 7. BATHTUB Model Calibration to Observed Total Phosphorus Data	19
Figure 8. BATHTUB Model Calibration to Observed Chlorophyll <i>a</i> Data	20
Figure 9. BATHTUB Model Calibration to Observed Secchi Depth Data	20

LIST OF TABLES

Table 1. WDNR 2012 303(d) Impaired waters listing for Musky Bay in Lac Courte Oreilles.....	2
Table 2. Summary of hypolimnetic dissolved oxygen in major basins and bays of LCO (June – October 2013).	7
Table 3. Estimated annual total phosphorus loads for major tributaries.....	9
Table 4. Land use percentages for other direct drainage areas...	11
Table 5. Baseline phosphorus export coefficients.	11
Table 6. Estimated annual flows and total phosphorus loads for direct drainage areas.	11
Table 7. Estimated annual total phosphorus loads for direct drainage areas.	13
Table 8. BATHTUB Model Options for Lac Courte Oreilles	16
Table 9. Predicted water quality benefits of meeting lake-wide average phosphorus goal.....	22
Table 10. Source reductions required to meet lake-wide average phosphorus goal.	23
Table 11. Wasteload Allocations to meet TMDL.....	23
Table 12. Load Allocations to meet TMDL.	24
Table 13. Source reductions required to meet lake-wide average phosphorus goal.	24



LIST OF APPENDICES

Appendix A: Lac Courte Oreilles Economic Survey and
Assessment

Appendix B: Phosphorus Site-Specific Criteria Proposal for: Lac
Courte Oreilles

Appendix C: Loss of Beneficial Uses, Musky Bay, Lac Courte
Oreilles

Appendix D: Quality Assurance Project Plan for 106 Water
Quality Monitoring Project Lac Courte Oreilles Reservation

Appendix E: Sediment Characteristics and Diffusive Phosphorus
Fluxes in Lac Courte Oreilles, Wisconsin

Appendix F: Lac Courte Oreilles Lake Management Plan



Blank page



1 Introduction

Lac Courte Oreilles (LCO) is a 5,039-acre drainage lake in Sawyer County, Wisconsin (Wisconsin Waterbody Identification Code 2390800). The lake has been classified as an Outstanding Resource Water (ORW) since 1993. Lac Courte Oreilles has a drainage area of approximately 68,990 acres (108 square miles) within the Upper Chippewa River Basin (Figure 1). The main tributaries to the lake are Grindstone, Osprey, and Whitefish Creeks.

Land use/land cover in the watershed is predominantly forested and open water/wetland; five cranberry bogs are located within the LCO direct drainage area that withdraw water from and discharge to the lake. With multiple sport fishes, LCO is a two-story fishery with a maximum depth of 90 feet and a mean depth of 34 feet. LCO is widely recognized for its exceptional recreational and economic benefits as it provides about \$700,000 annually through fishing trips to the region, with pursuits in Musky Bay contributing roughly 12% of that total (Pratt, 2013). The lake is central to the region's economy with real estate valued at over \$332 million, annual property taxes of \$2.9 million, supporting of local infrastructure, plus associated expenditures from residents and vacationers estimated to be about \$9.8 million to \$14.8 million per year (Wilson, 2010; Appendix A). LCO is also central to the culture of the Lac Courte Oreilles Band of Lake Superior Chippewa. One-third of Lac Courte Oreilles lake is located within reservation boundaries, with the rest of the lake located within the ceded territory.

Three major bays (Musky, Stuckey, and Northeast) and three major basins (West, Central, and East) comprise the lake (Figure 1). Most of these are classified as oligotrophic; however, Musky Bay has been characterized by eutrophic conditions in recent years (Wilson, 2011). In 2012, Musky Bay was placed on the Wisconsin Department of Natural Resources (WDNR) 303(d) impaired waters list for impairment to water quality use restrictions due to elevated total phosphorus (TP; Table 1). Recreational use has been limited in Musky Bay due to the presence of algal mats, as well as excessive growth of curly leaf pond weed. Elevated phosphorus in the other basins of the lake has resulted in increased oxygen demand and degraded conditions for the two-story fishery. In particular, phosphorus concentrations in Stuckey Bay are of concern for both fish and aquatic life uses and recreational use. West Basin is impacted by elevated phosphorus concentrations from both Stuckey Bay and Musky Bay.

The goal of this Total Maximum Daily Load (TMDL) is to restore and protect the attainment of beneficial uses throughout the lake by reducing phosphorus loadings to Lac Courte Oreilles. The phosphorus loads specified in this TMDL are designed to: decrease the frequency and severity of algal blooms in Musky Bay; increase dissolved oxygen levels throughout the lake sufficient to protect the two-story cold water fishery; stop eutrophication from proceeding in the west end of the lake, and protect this outstanding natural resource from further degradation.



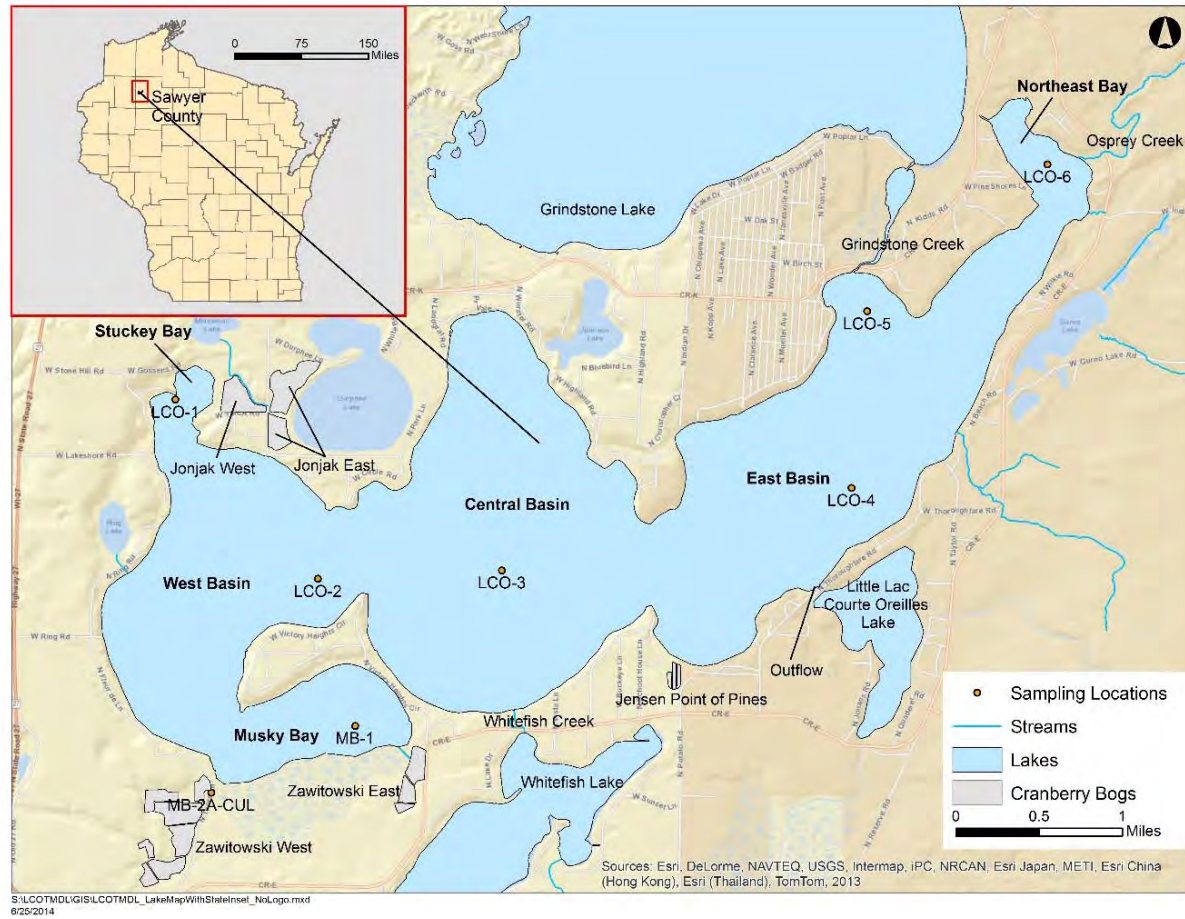


Figure 1. Location of Lac Courte Oreilles

Table 1. WDNR 2012 303(d) Impaired waters listing for Musky Bay in Lac Courte Oreilles

Local Waterbody Name	WBIC	Pollutant	Impairment Indicator
Musky Bay	2390800	Total Phosphorus	Water Quality Use Restrictions

2 Problem Statement

Water quality and the cold water fishery in LCO is threatened by ongoing excessive phosphorus loading. Sources of phosphorus to LCO include nearby forested and agricultural land uses, adjacent wetlands, shoreline development, inputs from adjacent cranberry bogs, atmospheric deposition, and phosphorus release from sediments in the lake. Water quality degradation has been most apparent in Musky Bay, which has seen shifts in vegetation composition and increased persistence of dense, floating algal mats (Fitzpatrick et al., 2003; Wilson, 2011). Consequently, WDNR included Musky Bay on its 2012 303(d) list of impaired waters. WDNR indicated that *“Total phosphorus concentrations exceed WisCALM listing thresholds for recreation use... Observed macrophyte density in Musky Bay is not representative of expected conditions and is in fact causing an impairment of the recreational use.”* U.S. Environmental Protection Agency approved Wisconsin’s 2012 303(d) list on June 25, 2014, concurring with WDNR’s listing of Musky Bay and its rationale for doing so.

Increased spatial distribution of floating algal mats and macrophytes has been observed in Musky Bay in recent years. Excessive algal growth results in depleted dissolved oxygen conditions from decomposition of dying algae, which also leads to degradation of substrate through deposition and accumulation of organic matter (Fitzpatrick, et al., 2003). Cumulatively, these conditions can be detrimental to suitable habitat conditions for fish spawning and refugia and have likely led to reduced fish populations in Musky Bay.

While water quality is fairly high in much of LCO, hypoxic conditions (< 2 mg/L) develop in the hypolimnion of some bays and basins during the summer stratification period, threatening cold water fish species, including cisco and whitefish, and limiting successful spawning of muskellunge. Continued loading of phosphorus to the major basins and bays of LCO at current rates will contribute to a trend of increasing summertime dissolved oxygen depletion in the hypolimnion through increased phytoplankton productivity and subsequent decay. Hypoxic conditions also lead to increased rates of internal loading of phosphorus from the sediments, which has been measured in laboratory experiments on intact sediment cores (James, 2013a; James, 2013b). These degraded conditions in LCO are likely to be amplified with ongoing climate change as watershed loads increase and surface waters warm resulting in further degradation of recreational uses and habitat suitable for cold water fisheries.

Water Quality Targets

Lac Courte Oreilles is designated by WDNR as an Outstanding Resource Water (ORW). As such, it is protected by Wisconsin’s antidegradation rule (WAC NR 207.03(3)), with the intent that water quality in the lake is not lowered; any new or expanded discharge would be required to discharge at background water quality levels. As a two-story cold water fishery, the current applicable statewide TP criterion in LCO is 15 $\mu\text{g/L}$ (WAC NR 102.06). However, this criterion does not consider the ORW designation of this resource nor the site-specific recreational and aquatic life uses and characteristics. To address these concerns, the Courte Oreilles Lakes Association (COLA), in cooperation with the Lac Courte Oreilles Band of Lake Superior Chippewa Indians (Tribe), developed a site-specific criterion (SSC) or water quality target for LCO consisting of a lake-wide average of 10 $\mu\text{g/L}$ TP (COLA, 2014; Appendix B). This target was set in order to restore and protect designated uses and comply with antidegradation for an ORW. More specifically, the lake-wide average target of 10 $\mu\text{g/L}$ TP is based on the following considerations:



1. Following commonly accepted limnological practice and terminology, the three bays (Musky, Stuckey, and Northeast) and three basins (West, Central, and East) comprise one lake referred to as Lac Courte Oreilles and are identified by one lake identification number (ID # 2390800);
2. All of the bays and basins are inter-connected and share one water level (relative to sea level except for short-term variations caused by wind, seiche, storm inflows etc.);
3. Documented impairments in Musky Bay even while the bay was meeting its WDNR-applied 40 µg/L total phosphorus criterion (Pratt, 2013; Appendix C);
4. The direct connection of Musky Bay to LCO and, therefore, its influence on water quality in the rest of LCO;
5. Stratification status of Musky Bay as “deep” based on temperature profiles collected in the bay;
6. Evidence of significant increases in phosphorus loading to LCO since pre-settlement conditions based on the sediment diatom record;
7. Despite attainment of current total phosphorus criteria (15 µg/L) in LCO, a biologic impairment exists in the lake due to dissolved oxygen concentrations below 6 mg/L in the hypolimnion, indicating negative impacts to the cold water fishery in LCO;
8. Dissolved oxygen levels in the flocculent sediment at the bottom of Musky Bay are below concentrations necessary for muskellunge egg survival during spawning season; and,
9. The need to proactively protect against future degradation of fish populations due to climate change through watershed management practices.

Based on a review of available scientific literature, 10 µg/L was selected for LCO as appropriate for protection of water quality and the cold water fishery. A thorough review of phosphorus, dissolved oxygen, secchi depth, and chlorophyll *a* levels and health of various cold and warm-water fish species in Minnesota lakes can be found in Heiskary and Wilson (2005) and Heiskary and Wilson (2008). The important findings from these studies that support the proposed 10 µg/L total phosphorus criterion for LCO are:

- Dissolved oxygen depletion occurs when total phosphorus concentrations are greater than 10 µg/L, which is often used as an upper bound for oligotrophic conditions. A study of phosphorus and hypolimnetic oxygen demand lakes in British Columbia found that cold-water salmonid fisheries were protected with total phosphorus levels ranging from 5 to 15 µg/L (Nordin, 1986).
- Whitefish and cisco are most abundant in a trophic state index (TSI) range of 30 to 40, which corresponds to total phosphorus levels of 6 to 12 µg/L.
- Typical concentrations of total phosphorus in Minnesota designated lake trout lakes is 9 to 16 µg/L. For the lakes exhibiting adequate refuge for lake trout, the summer average total phosphorus commonly ranged from 8 to 10 µg/L;
- The upper bound for total phosphorus concentrations sustaining lake trout is likely 15 µg/L.

Ultimately, phosphorus loading to LCO must be reduced to restore the water quality and biologic conditions in this rare ORW. The threat of negative impacts from climate change heightens this need. Therefore, this TMDL is developed to protect LCO for a lake-wide average concentration of 10 µg/L. Achieving this target will reduce the frequency and extent of algal blooms and lead to improvements in hypolimnetic dissolved oxygen concentration that is necessary for success and proliferation of the cold water fisheries.



Monitoring Background

The Lac Courte Oreilles Conservation Department (LCOCD) has been overseeing water quality sampling in LCO since 1996. Sampling is conducted by LCOCD under a Quality Assurance Project Plan approved by U.S. EPA (LCOCD, 2011; Appendix D). More intensive monitoring began in 2002 with increased frequency of sampling for TP, chlorophyll *a* and secchi depth in each of the major bays and basins. Monitoring locations are presented in Figure 1. Measurements for *in situ* temperature and dissolved oxygen were also collected at varying depths for representative measurements in the epilimnion, metalimnion, and hypolimnion. In most years, sampling was generally conducted bi-monthly from May–October. TP and chlorophyll *a* samples were collected from the surface with hypolimnetic sampling for TP occurring in 2002 and 2013.

Water quality was evaluated for the period defining the summer growing season following the 2014 WisCALM methodology (WDNR, 2013). The summer growing season for TP is defined as June 1 – September 15; and the summer growing season for chlorophyll *a* and secchi depth is defined as July 15 – September 15. No significant temporal trend in seasonal mean TP or chlorophyll *a* concentration was found in the bays or basins ($\alpha = 0.05$). Therefore, seasonal means for the period of 2002–2013 were calculated in the major bays and basins for TP, chlorophyll *a* and secchi depth. Additionally, an area-weighted lake-wide average was calculated for TP.

In general, TP (Figure 22) and chlorophyll *a* (Figure 33) concentrations were higher in Musky Bay than all other bays or basins. Consistent with this pattern, seasonal mean secchi depth was lowest in Musky Bay (Figure 44). The area-weighted lake-wide average TP of 12.5 $\mu\text{g/L}$ for this period exceeds the TMDL target of 10 $\mu\text{g/L}$ by 25%.

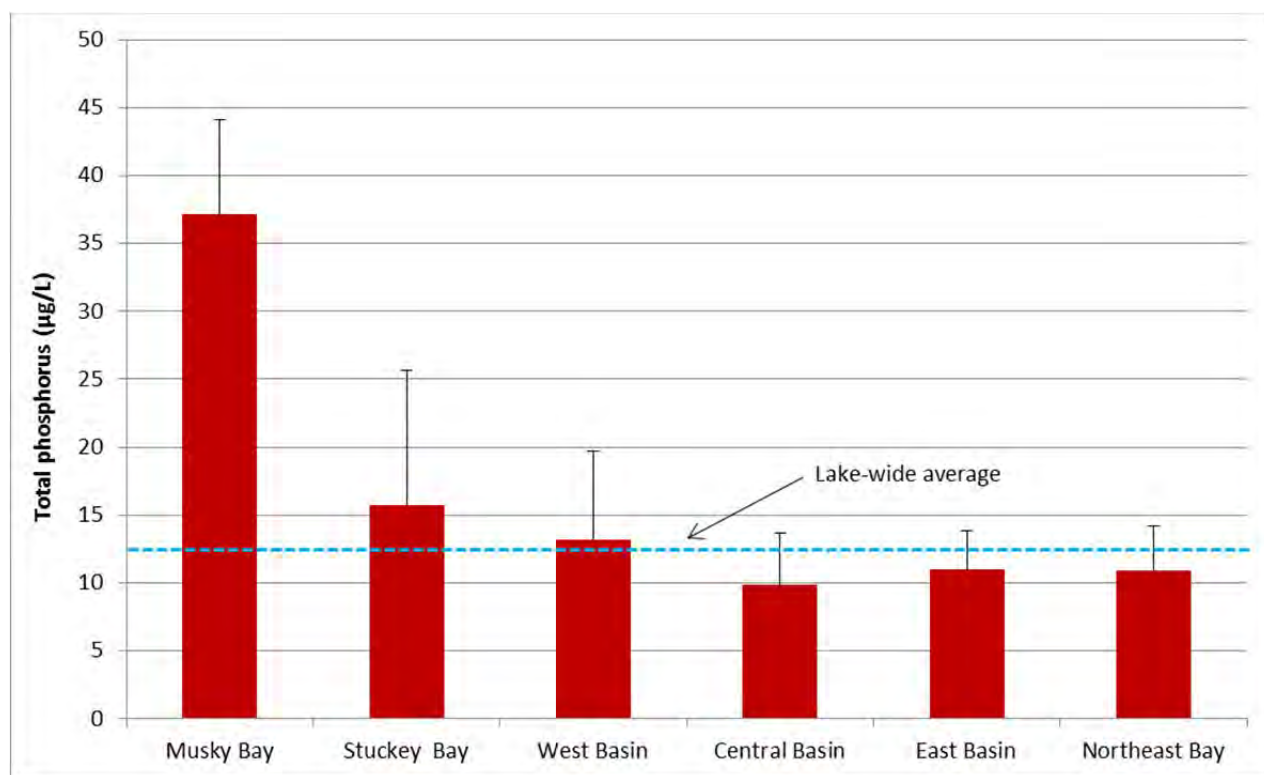


Figure 2. Seasonal mean total phosphorus (June 1–Sept 15) in major bays and basins of LCO (2002–2013). Errors bars indicate ± 1 SD



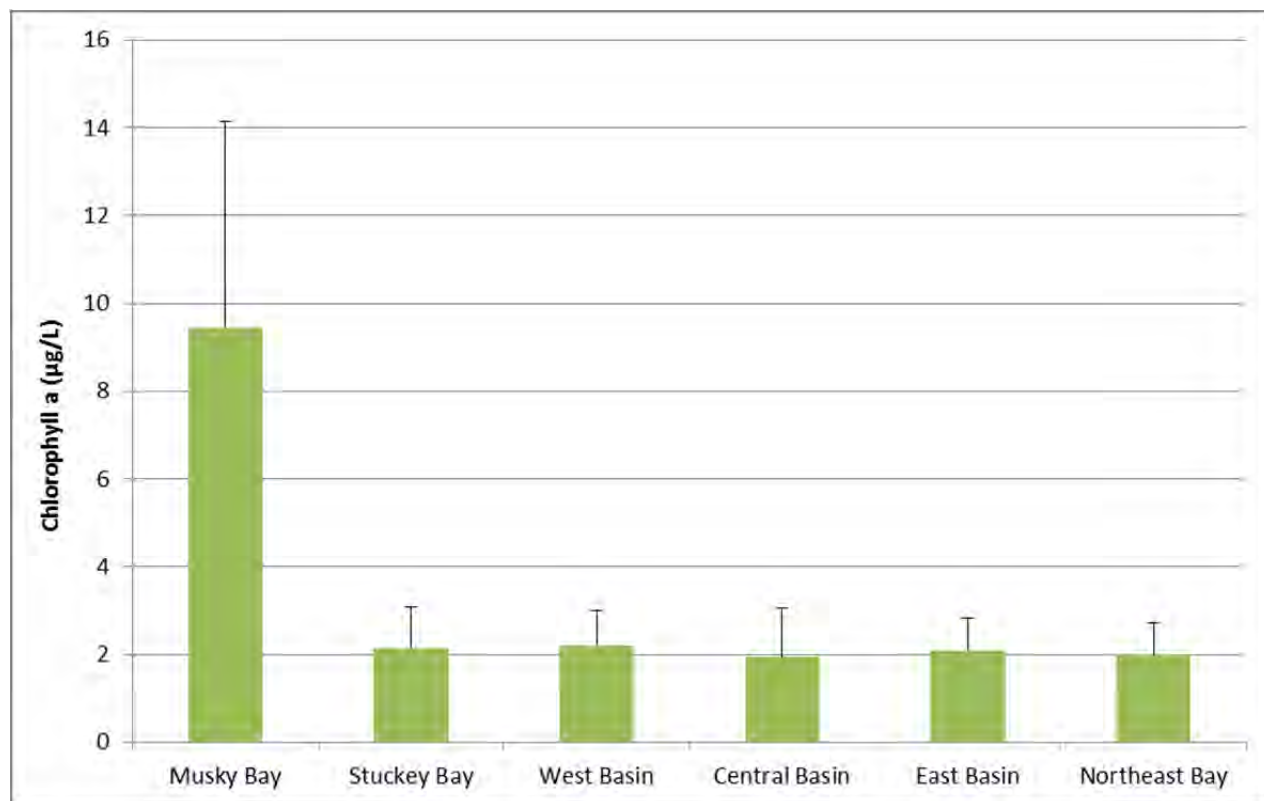


Figure 3. Seasonal mean chlorophyll *a* (July 15- Sept 15) in major basins and bays of LCO (2002-2013). Errors bars indicate ± 1 SD

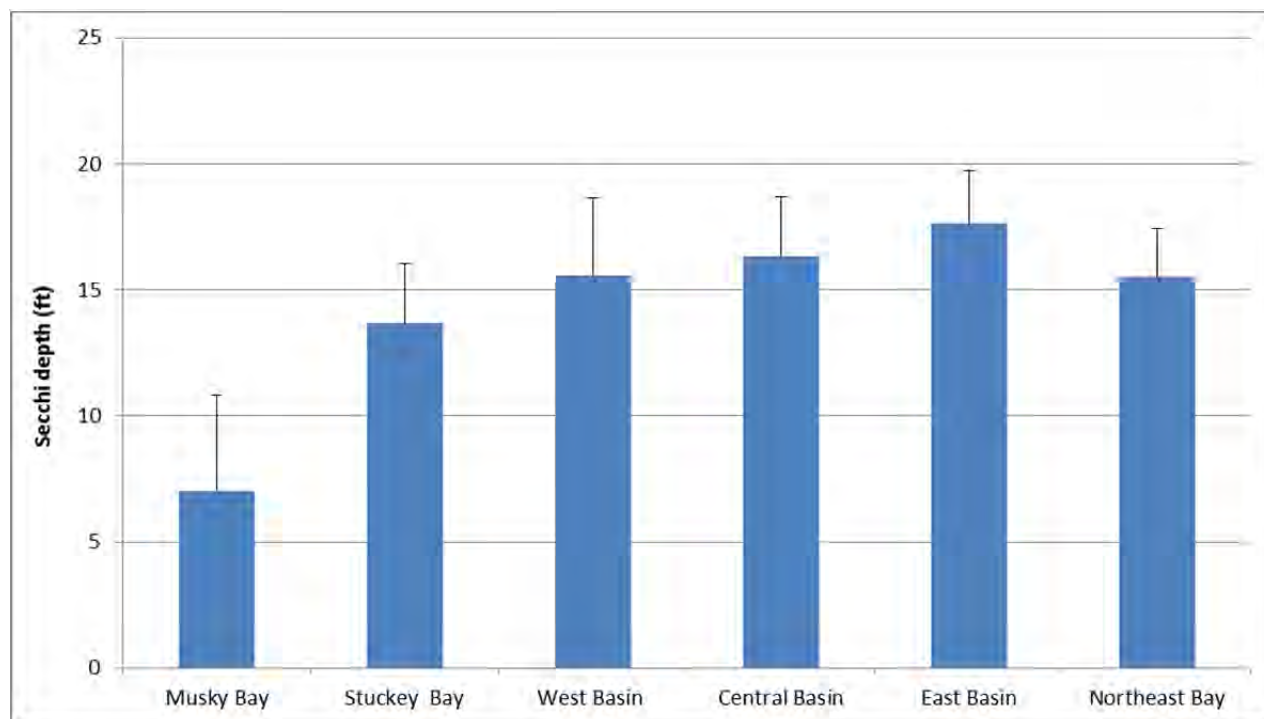


Figure 4. Seasonal mean secchi depth (July 15- Sept 15) in major basins and bays of LCO (2002-2013). Errors bars indicate ± 1 SD

Using temperature profiles collected in 2013, the average hypolimnetic dissolved oxygen (DO) concentration was determined for measurements collected after the onset on stratification, and the frequency of average hypolimnetic DO concentrations below 6 mg/L was calculated for each monitoring station (Table 2). The data indicates significant extent and frequency of DO concentrations depressed below the 6 mg/L threshold for protection of a cold water fishery.

Table 2. Summary of hypolimnetic dissolved oxygen in major basins and bays of LCO (June – October 2013)

Bay/Basin	Mean DO (mg/L)	Min DO (mg/L)	Max DO (mg/L)	Count of Daily Means	% Less than 6 mg/L
Musky Bay	3.24	0.85	9.87	11	82%
Stuckey Bay	8.44	6.11	11.24	9	0%
West Basin	2.23	0.04	8.43	19	84%
Central Basin	3.50	0.13	9.78	19	68%
East Basin	5.47	0.04	11.20	32 (two stations)	44%
Northeast Bay	7.99	5.95	11.22	14	7%



Blank page



3 Load Development

The development of estimates of phosphorus loads to LCO are described in this section. Loads were estimated for the following sources:

- Major tributary streams with sufficient monitoring data, including Grindstone Creek, Osprey Creek, and Whitefish Creek;
- Drainage areas outside of the major tributaries;
- Cranberry bogs; and
- Atmospheric deposition.

Subwatershed delineations for the major tributaries and the other direct drainage areas are presented in Figure 5. Loads resulting from the release of phosphorus from bottom sediments in LCO were included in the model development and calibration, and is discussed in Section 4 of this TMDL report.

Major Tributary Loads

Annual TP loads from the major tributaries to LCO Lac Courte Oreilles were estimated using monitoring data and the FLUX32 tributary loading model (Walker, 1985). The FLUX32 model was applied for Grindstone Creek, Osprey Creek, and Whitefish Creek subwatersheds based on tributary TP and flow monitoring data from 2013 collected by LCOCD. FLUX32 calculates tributary loads using six options; the flow weighted average method (Method 2) was selected as most appropriate for the available datasets. Results from the FLUX32 model are presented in Table 3.

Table 3. Estimated annual total phosphorus loads for major tributaries

Load Source	Bay or Basin Receiving Load	Total Flow (acre-ft)	Average TP Concentration (µg/L)	Annual TP Load (lb)
<i>Tributaries</i>				
Grindstone Creek	East Basin	15,543	20.5	921
Osprey Creek	Northeast Bay	1,393	55.5	194
Whitefish Creek	Central Basin	13,434	20.4	683



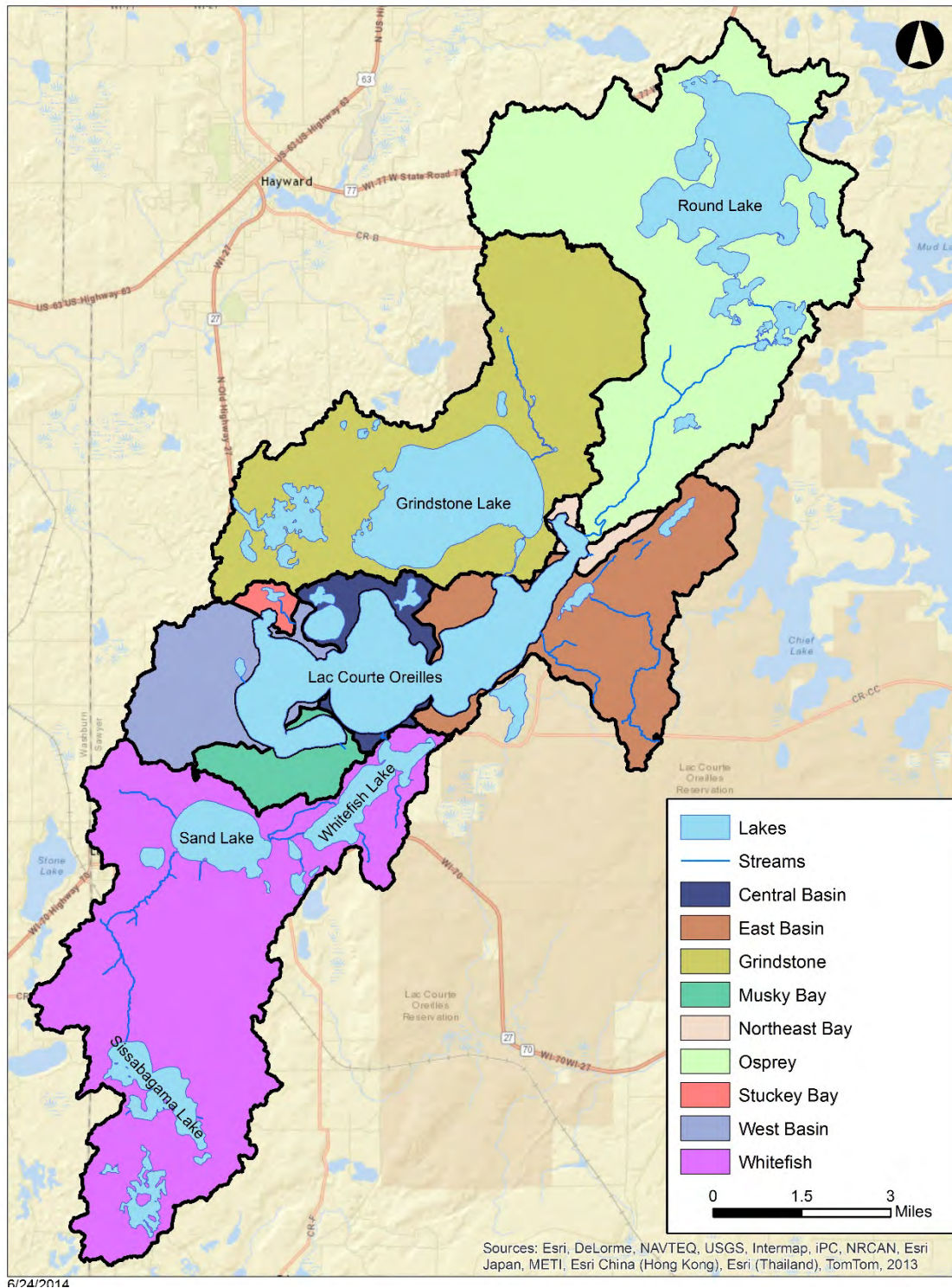


Figure 5. Subwatershed delineations

Other Direct Drainage Area Loads

Loading from areas draining to LCO outside of the three major tributaries was determined using NLCD 2006 land use percentages (agriculture, urban, grassland, forest, shrubland, open water) and baseline export coefficients specific to each land use. Figure 6 presents the land use designations in the watershed. Note that in practice, the pasture and cultivated cropland covers in the watershed are predominantly corn and soybean rotations with occasional hay and alfalfa. Table 4 presents the percentage of each land use type in the drainage areas. Baseline export coefficients were taken from the Lake St. Croix TMDL (WDNR and MPCA, 2012) and are presented in Table 5. Estimated annual phosphorus loads for each of the direct drainage areas is given in Table 6.

Table 4. Land use percentages for other direct drainage areas

Direct Drainage Area	Total Area (acres)	Percent Agriculture	Percent Urban	Percent Grassland	Percent Forest	Percent Shrubland	Percent Open Water
West Basin	3,100	13%	8%	41%	33%	0%	4%
Central Basin	1,336	1%	15%	6%	45%	0%	33%
East Basin	5,898	0%	9%	1%	75%	1%	13%
Musky Bay	1,350	3%	8%	23%	45%	0%	21%
Stuckey Bay	328	2%	11%	10%	59%	0%	17%
Northeast Bay	461	1%	9%	0%	75%	0%	15%

Table 5. Baseline phosphorus export coefficients

Land Use Category	Baseline Export Coefficient (lbs/ac/yr)
Agriculture	0.561
Urban	0.561
Grassland	0.197
Forest	0.088
Shrubland	0.088
Open Water	0.006

Table 6. Estimated annual flows and total phosphorus loads for direct drainage areas

Direct Drainage Area	Annual Flow (acre-ft)	Unit Area Load (lb/ac/yr)	Annual TP Load (lb)
West Basin	2,335	0.233	722
Central Basin	1,416	0.143	191
East Basin	440	0.121	716
Musky Bay	1,017	0.148	200
Stuckey Bay	348	0.148	48
Northeast Bay	34	0.121	55



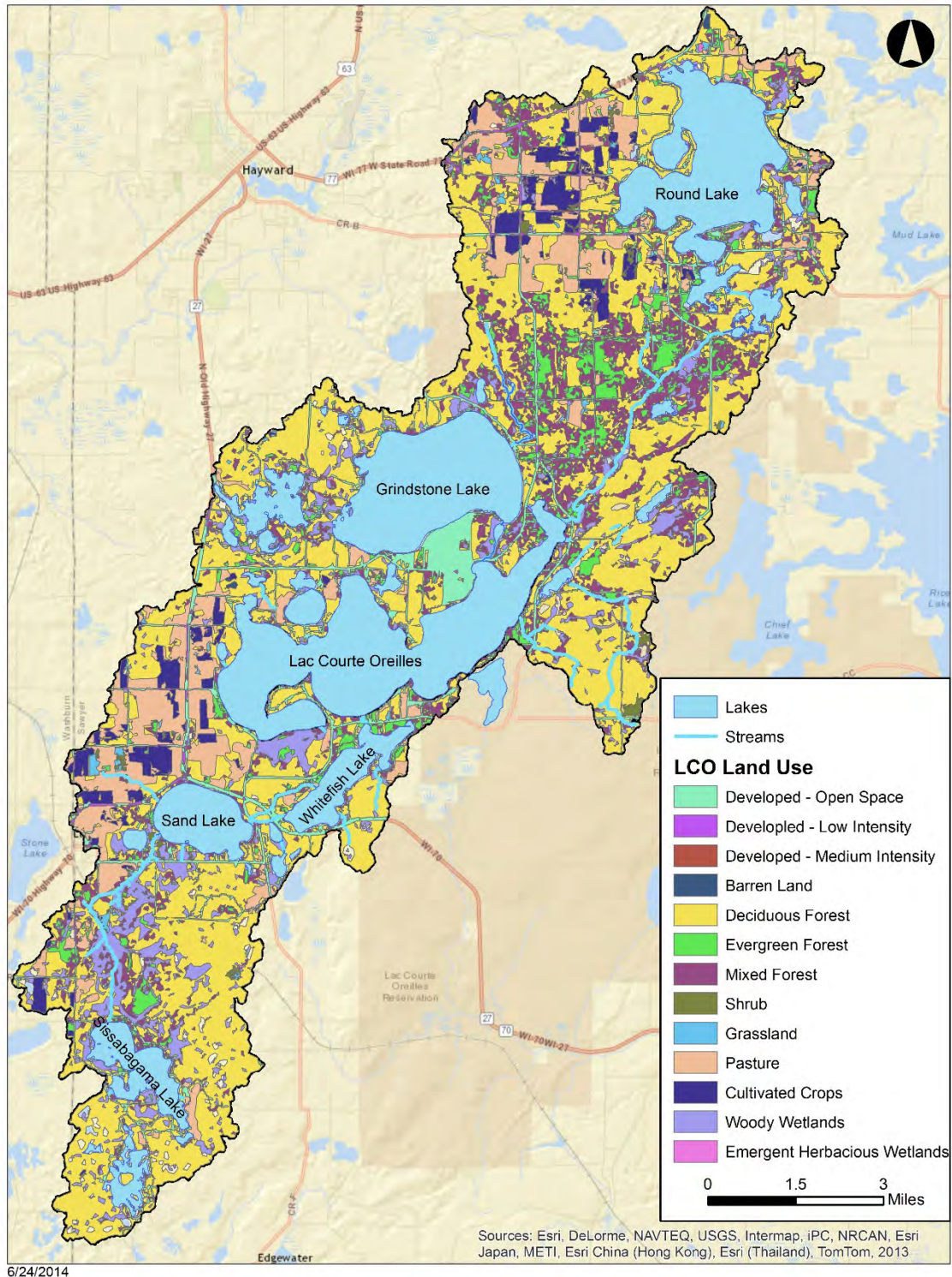


Figure 6. Watershed land use designations

Cranberry Bog Loads

TP loading from cranberry bogs was calculated using data from samples collected at station MB-2A-CUL (Figure 1). This station represents cranberry bog discharges into western Musky Bay. Concentrations from this sampling location were assumed to be representative of discharges from all five cranberry bogs that discharge to LCO. Samples were collected at least once monthly from March – October 2013, with additional sampling during the spring runoff period and storm events.

TP loads were estimated for several types of operational discharge events (spring overwinter crop protection and sprinkling or flooding; fall frost protection sprinkling or flooding; and fall harvest discharge) as well as precipitation driven runoff events. Water volumes for each operational discharge were calculated using the bog area (as calculated in GIS from aerial photographs) and an assumed water depth. For both spring and fall operational discharges, three events at 1-foot water depth were assumed to occur. The harvest discharge occurred once in the late fall and the water depth was assumed to be three feet. An average TP concentration was calculated from the sampling data for each type of event using field notes that indicated when the bog was discharging. Average spring and fall operational discharge concentrations were calculated to be 200 and 100 µg/L, respectively.

To represent TP loads resulting from precipitation driven discharges from the bogs, the Natural Resources Conservation Service (NRCS) Curve Number (CN) method (USDA, 1986) was used. A CN of 77.75 was applied corresponding to the average CN for hydrologic soil groups for the land use “Agriculture, non-row crops,” consistent with the approach by WDNR (2014) for cranberry bogs using curve numbers from MacEnroe and Gonzalez (2003). The annual runoff volume was calculated using the bog area, total annual precipitation, and the CN of 77.75. Total annual precipitation for 2013 was 40.71 inches from the Couderay 7 W weather station (USC00471847) located six miles from LCO (NOAA, 2014). An average TP concentration in the precipitation runoff was calculated using field notes that indicated dates of storm water discharge from the bog. The average TP discharge concentration during runoff events was calculated to be 158 µg /L.

Table 7. Estimated annual total phosphorus loads for direct drainage areas

Parameter	Musky Bay West Bog	Musky Bay East Bog	Jonjak West Bog	Jonjak East Bog	Point of Pines Bog	Totals
Bog Area (ac)	73	23	22	45	6	169
Total Spring Load (lbs)	119	37	36	73	9	275
Total Fall Load (lbs)	60	19	18	37	5	138
Total Fall Harvest Load (lbs)	60	19	18	37	5	138
Total Runoff Load (lbs)	18	6	5	11	1	41
Annual Total Phosphorus Load (lbs)	257	80	77	158	20	592

Atmospheric Loads

Loads from atmospheric phosphorus deposition directly into LCO were specified using data reported by Robertson, et al. (2009) for nearby Whitefish Lake of 17.047 mg/m²-yr. This results in a TP loading to LCO via atmospheric deposition of 765 lbs/yr.



Blank page



4 Water Quality Model Development

Water quality models are used to define the relationship between pollutant loading and the resulting water quality. This TMDL is based upon the BATHTUB model. The development of the BATHTUB model is described in the following sections, including information on:

- Model selection
- Model inputs
- Model calibration

Model Selection

The BATHTUB water quality model (Walker, 1985) was used to define the relationship between external phosphorus loads and the resulting total phosphorus concentration, chlorophyll *a* concentration, and secchi depth. The BATHTUB model was selected because it provides an optimal balance between data requirements and technical rigor. BATHTUB has been used in other Wisconsin lake modeling projects, as well as numerous lake and reservoir TMDLs across the country. It has been cited as an effective tool for lake and reservoir water quality assessment and management (Ernst et al., 1994).

Model Inputs

This section gives an overview of the model inputs required for BATHTUB application and how they were derived. The following categories of inputs are required for BATHTUB:

- Model options
- Global variables
- Segmentation
- Dispersion coefficients
- Phosphorus loads

Model Options

BATHTUB provides a multitude of model options to estimate nutrient concentrations in a lake or reservoir. Model options were applied as shown in Table 88 for LCO, with the rationale for these options discussed as follows. No conservative substance was being simulated for the lake, so this option was not needed. The Canfield and Bachman model was used to simulate phosphorus. Nitrogen was not simulated since phosphorus is the nutrient of concern. Chlorophyll *a* was simulated using the Jones and Bachman model. Transparency was simulated using the Total P model. Longitudinal dispersion was specified using the Input Exchange option, with dispersion inputs based upon the results of an EFDC hydrodynamic model developed specifically for LCO (discussed below). Phosphorus calibrations were based on decay rates. No nitrogen calibration was required. Finally, the use of availability factors was not required, and observed concentrations were used to generate mass balance tables for the lakes.



Table 8. BATHTUB Model Options for Lac Courte Oreilles

Model	Model Option
Conservative substance	Not computed
Total phosphorus	Canfield and Bachman
Total nitrogen	Not computed
Chlorophyll-a	Jones and Bachman
Transparency	Total P
Longitudinal dispersion	Input Exchange
Phosphorus calibration	Decay Rates
Nitrogen calibration	None
Availability factors	Ignored
Mass-balance tables	Use observed concentrations

Global Variables

The global variables required by BATHTUB consist of:

- The averaging period for the analysis
- Precipitation, evaporation, and change in lake levels
- Atmospheric phosphorus loads

BATHTUB is a steady state model, whose predictions represent concentrations averaged over a period of time. A key decision in the application of BATHTUB is the selection of the length of time over which inputs and outputs should be modeled. The length of the appropriate averaging period for BATHTUB application depends upon what is called the nutrient residence time, i.e. the average length of time that phosphorus spends in the water column before settling or flushing out of the lake. Guidance for the BATHTUB model recommends that the averaging period used for the analysis be at least twice as large as nutrient residence time for the lake of interest. Initial simulations for LCO showed a phosphorus residence time on the order of one year, so a two year averaging period was used.

Precipitation inputs were taken from the Couderay 7 W weather station (USC00471847). This resulted in a typical annual precipitation input of 32 inches for the lake. Evaporation was set to equal precipitation.

Finally, atmospheric phosphorus loads were specified using data reported by Robertson, et al. (2009) for nearby Whitefish Lake of 17.047 mg/m²-yr.)

Segmentation

BATHTUB provides the capability to divide the lake under study into a number of individual segments, allowing prediction of the change in phosphorus concentrations over the length of each basin or bay. The segmentation scheme selected for Lac Courte Oreilles was designed to provide one segment for each of the three primary lake basins (East, Central, and West), and distinct segments for each of the major embayments (Musky, Stuckey, and NE Bays).

BATHTUB requires that a range of inputs be specified for each segment. These include segment surface area, length, total water depth, and depth of thermocline and mixed layer. Segment-specific values for segment depths were calculated from segment volumes divided by surface areas. Segment lengths and surface areas were calculated using GIS.



Dispersion Coefficients

BATHTUB describes the degree of mixing that occurs between model segments through the use of dispersion coefficients. BATHTUB provides the capability of estimating these dispersion coefficients using empirical equations from the scientific literature. BATHTUB also allows the user to manually specify these dispersion coefficients in situations where the model user has better site-specific information to define this mixing. The latter approach was taken for LCO, because the rate of mixing controls:

1. The extent to which concentrations in the bays are caused solely by loads directly to the bays, versus concentrations in the main basins; and
2. The extent to which concentrations in the bays are expected to differ from concentrations in the main lake basins for a given loading scenario.

A fine-scale hydrodynamic model was developed for LCO to directly predict the amount of mixing between segments. The hydrodynamic model was based upon the Environmental Fluid Dynamics Code (EFDC), an EPA-supported modeling framework. Application of the EFDC model consisted of the following steps:

- Development of a model grid
- Comparison of model predictions to surface temperature data
- Application of the model to define mixing between bays and basins
- Translation of EFDC outputs into dispersion coefficients for use with BATHTUB

Development of the model grid consisted of digitizing the bathymetric map of LCO, then developing a curvilinear segmentation scheme that captured the variation of the bathymetry. The resulting grid has 2,125 cells horizontally; when applied in three-dimensional mode there are a total of 21,250 cells.

Once the model grid was established, EFDC was applied using observed 2012 climatic data (from Sawyer County Airport and the Rice Lake solar radiation site) as model inputs. Surface temperatures predicted by EFDC were successfully compared to observed data from multiple lake stations to demonstrate the reliability of model predictions.

The next step of EFDC application consisted of a dye tracer simulation to define mixing between bays and basins. The model was vertically condensed into two dimensions for computational purposes, and a slug of conservative dye was entered into the model at Musky Bay on June 1. EFDC predicted the rate at which this dye spread throughout the rest of the lake over the remainder of the year. Finite difference equations were developed to allow for the estimation of the dispersion taking place at each of the BATHTUB model segment interfaces.

The final step consisted of translating the EFDC outputs into dispersion coefficients for use with BATHTUB. The mixing coefficients determined above were in units of cubic meters per day, while BATHTUB requires dispersion coefficients be specified in units of cubic hectometers/year. A unit conversion factor of 0.000365 was applied to convert the EFDC estimates into values used in BATHTUB.

Phosphorus Loads

BATHTUB requires flow and nutrient concentrations for each tributary under consideration. Three tributaries were described: Grindstone Creek (discharging to East Basin), Whitefish Creek (discharging to Central Basin) and Osprey Creek (discharging to NE Bay.) Flows and TP concentrations for each tributary were estimated using data collected by the LCOCD as described in Section 3.

In addition to the above tributary loads, direct drainage and cranberry bog inputs were specified for each lake segment based on the load estimation described in Section 3.



Model Calibration

BATHTUB model calibration consists of:

1. Applying the model with all inputs specified as above
2. Comparing model results to observed phosphorus data
3. Adjusting model coefficients to provide the best comparison between model predictions and observed phosphorus data.
4. Comparing model results to observed chlorophyll *a* data
5. Adjusting model coefficients to provide the best comparison between model predictions and observed chlorophyll *a* data.
6. Comparing model results to observed secchi depth data
7. Adjusting model coefficients to provide the best comparison between model predictions and observed secchi depth data.

The BATHTUB model was initially applied with the model inputs as specified above. Observed data from Lac Courte Oreilles for the years 2002 and 2013 were used for calibration purposes, consistent with the assumption of a multiple-year averaging period for BATHTUB.

BATHTUB was first calibrated to match the observed average total phosphorus concentrations in each of the model segments. The calibration strategy consisted of using a single lake-wide calibration coefficient, rather than making calibration adjustments on a segment by segment basis. Model results in all six segments initially over-predicted the observed phosphorus data. Selection of a calibration coefficient of 1.55 resulted in an acceptable fit to the observed total phosphorus data in every modeled segment except Musky Bay, where the model under-predicted the observed phosphorus concentration. Phosphorus loss rates in BATHTUB rates reflect a typical “net settling rate” (i.e. settling minus sediment release) observed over a range of water bodies. Under-prediction of observed phosphorus concentrations can occur in cases of elevated phosphorus release from lake sediments. The mismatch between model and data for Musky Bay was corrected during the calibration process via the addition of an internal phosphorus load of 0.1 mg-P/m²-day to the Musky Bay segment. The additional sediment phosphorus flux is consistent with the phosphorus flux measurement conducted by James (2013a; Appendix E), who measured sediment phosphorus fluxes in Musky Bay of 0.06 – 0.31 mg-P/m²-day during oxic conditions, and sediment phosphorus fluxes of 0.46 – 2.96 mg-P/m²-day during anoxic conditions. Because the BATHTUB input for sediment phosphorus flux represent the incremental increase in flux over “typical” lakes, observed sediment flux data provide an upper bound for the BATHTUB input. The BATHTUB input of 0.1 mg-P/m²-day, which is equivalent to 90 lbs TP per year, is much lower than the majority of the observed range, supporting its appropriateness. The resulting predicted total phosphorus concentration is shown in Figure 77.



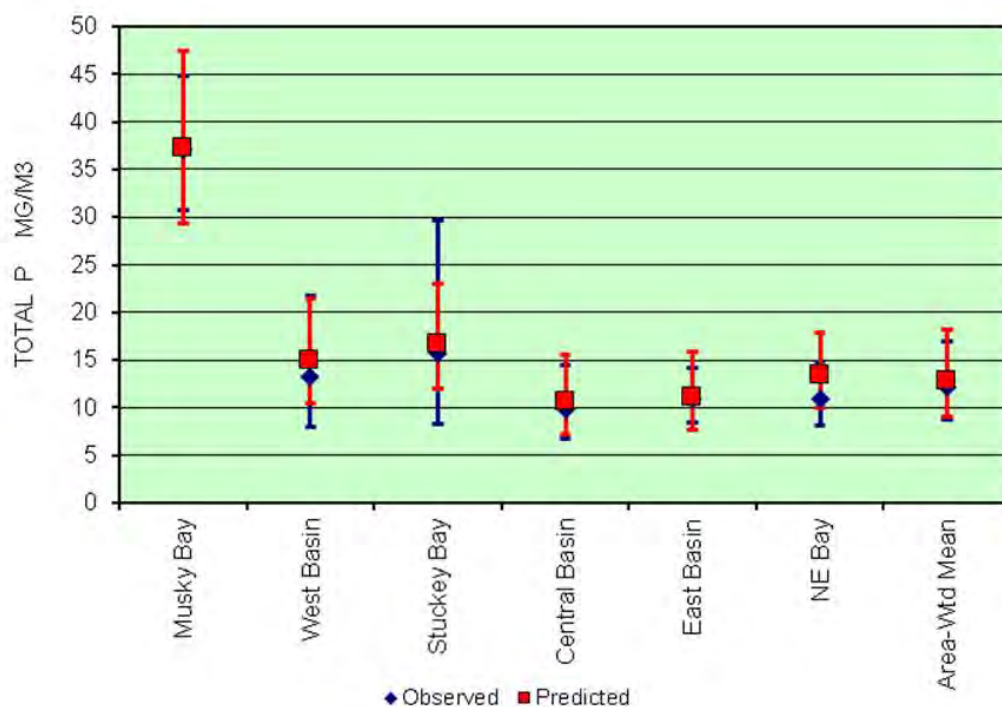


Figure 7. BATHTUB Model Calibration to Observed Total Phosphorus Data

BATHTUB was next calibrated to match the observed average chlorophyll *a* concentrations in each of the model segments. The calibration strategy consisted of using a single lake-wide calibration coefficient, rather than making calibration adjustments on a segment by segment basis. Model results in all six segments initially over-predicted the observed chlorophyll *a* data. Selection of a calibration coefficient of 0.6 resulted in an acceptable fit to the observed total chlorophyll *a* data in every modeled segment, as shown in Figure 8.

The final aspect of BATHTUB calibration corresponded secchi depth transparency. The calibration strategy again consisted of using a single lake-wide calibration coefficient, rather than making calibration adjustments on a segment by segment basis. Model results in all six segments initially under-predicted the observed secchi depth data. Selection of a calibration coefficient of 1.8 resulted in an acceptable fit to the observed secchi depth data in every modeled segment, as shown in Figure 9.

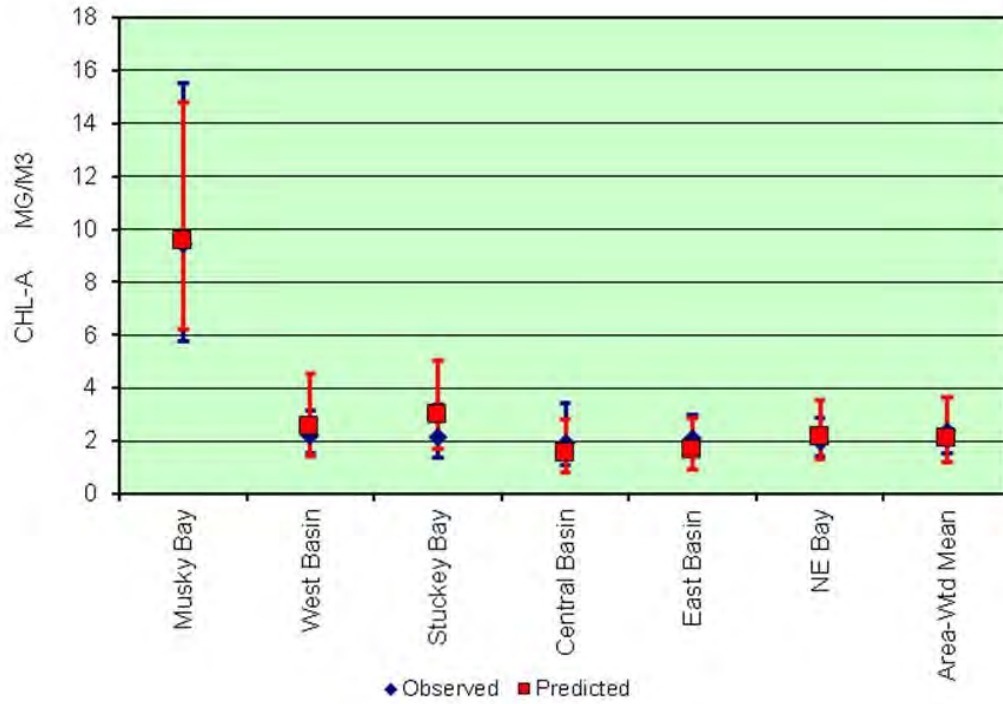


Figure 8. BATHTUB Model Calibration to Observed Chlorophyll a Data

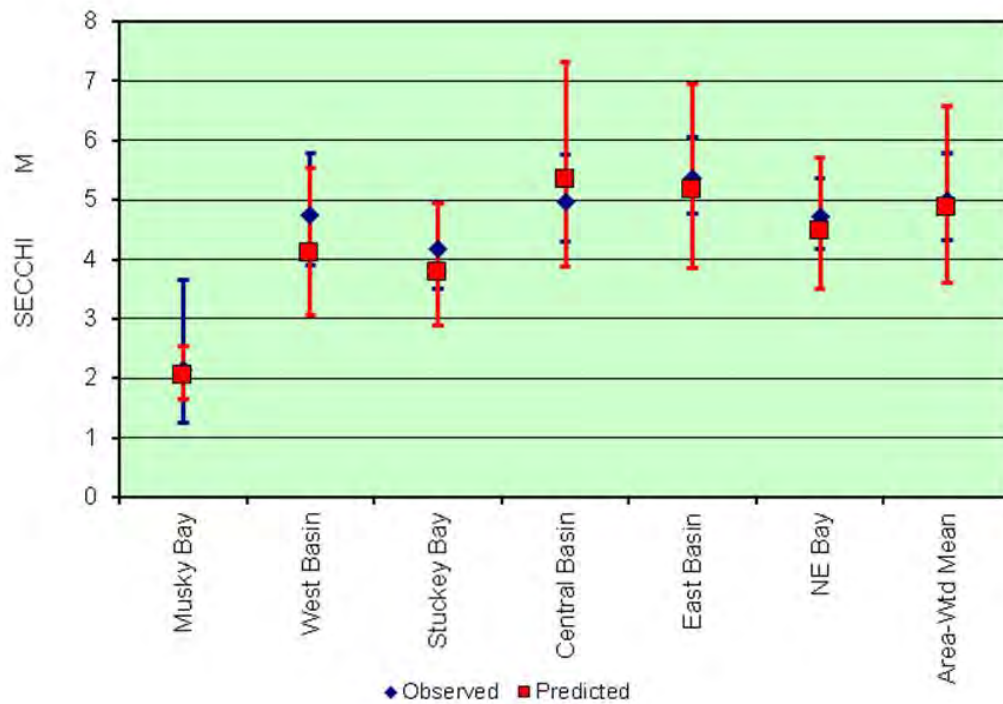


Figure 9. BATHTUB Model Calibration to Observed Secchi Depth Data

5 TMDL Development

Linkage Analysis

Establishing a link between watershed characteristics and resulting water quality is a crucial step in TMDL development. The primary concern for LCO is the amount of phosphorus entering the lake through direct runoff, tributaries, and cranberry bog discharges, as well as excess phosphorus releases from bottom sediments in Musky Bay. Phosphorus enters the lake in both dissolved and sediment-bound form from these sources. Excess phosphorus loading causes eutrophication of lakes, characteristics of which are increased macrophyte and algal growth and hypolimnetic oxygen depletion.

Water Quality Goals

The goal of this TMDL is to reduce external phosphorus loadings to LCO in order to support LCO's designated fish and aquatic life use of a two-story cold water fishery and to support recreational use of the lake. The water quality goal that has been established to support designated uses and to comply with antidegradation in this ORW is a lake-wide summer average epilimnetic TP concentration of 10 µg/L, which is the proposed site-specific phosphorus criterion for the lake. Reductions in chlorophyll *a* concentrations, improvements in water clarity (as measured by secchi depth), and reductions in hypolimnetic oxygen demand rates are expected as benefits of achieving this water quality target.

The water quality goal was set based on the proposed phosphorus site-specific criterion for LCO, review of literature on water quality requirements for cold water fisheries health, and stakeholder input.

The BATHTUB model was used to determine the phosphorus load reductions necessary to achieve the goal. Results of the BATHTUB model application indicates that, under existing phosphorus loading conditions of 5,178 lbs/yr, the lake-wide average epilimnetic TP concentration is 12.8 µg/L, 28% higher than the goal of 10 µg/L. BATHTUB model results for load reduction scenarios show that reducing the phosphorus load by 1,297 lbs/yr, or 25%, to 3,881 lbs/yr results in attainment of the lake-wide average TP concentration of 10 µg/L. Attaining this lake-wide average TP goal results in water quality improvements at varying levels throughout the lake. The improvement in TP concentrations, chlorophyll *a* concentrations, secchi depth, and hypolimnetic oxygen demand are presented in Table 9.



Table 9. Predicted water quality benefits of meeting lake-wide average phosphorus goal

	Lake-wide Average	Musky Bay	Stuckey Bay	West Basin	Central Basin	East Basin	Northeast Bay
Total Phosphorus (µg/L)							
Baseline	12.8	37.3	16.7	14.9	10.6	11.0	13.4
Goal Attainment	10.0	15.1	11.0	10.7	8.9	9.7	12.1
% Improvement	22%	60%	34%	28%	16%	12%	10%
Chlorophyll <i>a</i> (µg/L)							
Baseline	2.1	9.6	3.0	2.5	1.5	1.6	2.1
Goal Attainment	1.4	2.6	1.6	1.5	1.2	1.3	1.9
% Improvement	33%	73%	47%	40%	20%	19%	10%
Secchi Depth (m)							
Baseline	4.9	2.0	3.8	4.1	5.3	5.2	4.5
Goal Attainment	5.6	4.1	5.2	5.3	6.1	5.7	4.8
% Improvement	14%	105%	37%	29%	15%	10%	7%
Hypolimnetic Oxygen Demand (mg/L/day)							
Baseline	0.132	0.282	0.103	0.148	0.114	0.123	0.070
Goal Attainment	0.116	0.183	0.084	0.126	0.104	0.116	0.067
% Improvement	12%	35%	18%	15%	8%	6%	5%

Loading Capacity

The loading capacity defines the maximum loading allowable for a waterbody to achieve the water quality goals. As stated previously, the loading capacity to achieve the water quality goal of a lake-wide average TP concentration of 10 µg/L was 3,881 lbs/yr TP. The total loading capacity for the TMDL is defined as the sum of the wasteload allocation (WLA) for point sources, the load allocation (LA) for nonpoint sources¹, and a margin of safety (MOS) and is generally described with the following equation:

$$\text{TMDL Load Capacity} = \text{WLA} + \text{LA} + \text{MOS}$$

Required reductions of individual sources are shown in Table 10. The allocation of the allowable phosphorus load to each source, and the required reductions, are discussed below.

¹ COLA is not aware of any determination by WDNR, U.S. EPA, or any other entity that cranberry discharges are nonpoint discharges.



Table 10. Source reductions required to meet lake-wide average phosphorus goal

Loading Source	Baseline Load (lbs)	Reduction Needed to Meet Target		Reduction to Address Margin of Safety (lb)	Allowable Load to Meet TMDL (%)	Reduction Needed to Meet TMDL (%)
		(%)	(lb)			
Grindstone Creek	921	10	92	0	829	10
Osprey Creek	194	0	0	0	194	0
Whitefish Creek	683	20	137	0	547	20
Direct Drainage Areas	1,933	20	387	130	1,417	27
Cranberry Bogs	592	100	592	0	0	100
Atmospheric Deposition	765	0	0	0	765	0
Musky Bay Excess Internal Load	90	100	90	0	0	100
Total	5,178	25	1,297	130	3,751	28

Wasteload Allocation

There are five cranberry bogs that discharge to LCO with a total annual phosphorus load of 592 lbs. The wasteload allocation for these discharges is set to zero. A total reduction of 100% of the TP load from each cranberry discharge is required to meet this TMDL.

Table 11. Wasteload Allocations to meet TMDL

Point source	Bay or Basin Receiving Discharge	Current Load (lb/yr)	Wasteload Allocation (lb/yr)	% Reduction Needed
Musky Bay West	Musky Bay	257	0	100%
Musky Bay East	Musky Bay	80	0	100%
Jonjak West	Stuckey Bay	77	0	100%
Jonjak East	West Basin	158	0	100%
Point of Pines	East Basin	20	0	100%

If any additional point source discharges are proposed in this watershed, an effluent limit of zero phosphorus would need to be included in the Wisconsin Pollution Discharge Elimination System (WPDES) permit. A zero phosphorus discharge would be necessary because of LCO's status as an ORW.

Load Allocation

The load allocation for LCO was developed based on BATHTUB model simulations and local knowledge and expertise of feasible reductions that may be made. The nonpoint sources to LCO and their associated load allocations are given in Table 12.



Table 12. Load Allocations to meet TMDL

Loading source	Current Load (lb/yr)	Load Allocation (lb/yr)	% Reduction Needed
Direct drainage (all bays/basins)	1,933	1,546	20%
Grindstone Creek	921	829	10%
Osprey Creek	194	194	0%
Whitefish Creek	683	547	20%
Atmospheric load	765	765	0%
Musky Bay Excess Internal Load	90	0	100%

The load allocations assume that the excess sediment phosphorus flux in Musky Bay, which is specified in the BATHTUB model as 0.01 mg/sq.m./day or 90 lbs per year, is eliminated through in-lake treatment. This internal loading rate in Musky Bay is the sediment flux in excess of “normal” flux rates, as described in Model Calibration. The load allocation for direct drainage areas will be further reduced to include a margin of safety, as described below.

Margin of Safety

The MOS, which is a required component of the TMDL, accounts for uncertainty in the relationship between water quality and pollutant loads. The MOS can be either explicitly defined during allocation of loads or implicitly accounted for through conservative assumptions made during load development and water quality model application. This TMDL includes a MOS that is 10% of the loading reduction required to reach the water quality target, or 130 pounds. The MOS was added to the load reductions necessary for direct drainage areas, resulting in an allowable load to meet the TMDL of 1,417 lbs/yr, or a 517 lbs/yr (27%) reduction from baseline loads (Table 13). Reductions from atmospheric loading and Osprey Creek are not likely, and additional reductions from Grindstone Creek and Whitefish Creek are likely not feasible. Therefore, the MOS was only applied to the direct drainage sources.

Table 13. Source reductions required to meet lake-wide average phosphorus goal

Loading Source	Baseline Load (lbs)	Reduction Needed to Meet Target		Reduction to Address Margin of Safety (lb)	Allowable Load to Meet TMDL (%)	Reduction Needed to Meet TMDL (%)
		(%)	(lb)			
Direct Drainage Areas	1,933	20	387	130	1,417	27

Seasonal Variation

The TMDL includes consideration of seasonal variation. The BATHTUB model used for the phosphorus TMDL is designed to evaluate seasonal to annual loads. The seasonal loading analysis that was used is appropriate due to the long response time between phosphorus loading and biotic response. LCO has a phosphorus residence time on the order of one year. Also, BATHTUB is a steady state model, whose predictions represent concentrations averaged over a period of time. This is consistent with the WisCALM methodology for assessing lakes for eutrophication, using a seasonal averaging period from June to September.



Reasonable Assurance

The Clean Water Act requires that states provide a “reasonable assurance” that the TMDL will be implemented. Reasonable assurance for implementation of activities to meet this TMDL will be provided through continued cooperation between WDNR, COLA, LCOCD, and Sawyer County. Participation of cranberry bog owners and other agricultural owners will also be critical to achieving the water quality goals. Due to its status as an ORW, implementation activities to attain this TMDL should be given priority for local, state, or federal funding.

Reasonable assurance for this TMDL will be provided through a variety of voluntary and/or regulatory means. The TMDL will be implemented through enforcement of current regulations, financial incentives and various local, state and federal pollution control programs. Some of these programs are:

- Wisconsin Administrative Code NR151 identifies performance standards and prohibitions to control polluted nonpoint source runoff. The rule also sets urban performance standards
- The WDNR and Sawyer County Land Conservation Department (LCD) will implement agricultural and non-agricultural performance standards and manure management prohibitions to address sediment and nutrient loadings in the LCO watershed. Many landowners voluntarily install BMPs to help improve water quality and comply with the performance standards. Cost sharing may be available for many of these BMPs. In some cases, farmers will not be required to comply with the agricultural performance standards and prohibitions unless they are offered at least 70% in cost sharing funds. If cost-share money is offered but not accepted, those in violation of the standards will be required to implement BMPs to comply with the rule.
- Targeted Runoff Management (TRM) Grants – The Sawyer County LCD may apply for TRM grants through the WDNR. These grants are competitive financial awards to support small-scale, short term projects (up to 24 months) to reduce runoff pollution. Both urban and agricultural projects can be funded through TRM grants which require a local contribution to the project. The state cost share maximum is \$150,000 per grant. Projects that correct violations of the performance standards and prohibitions and reduce runoff pollution to impaired waters are a high priority for this grant program.
- The Sawyer County Shoreland Zoning Ordinance requires an intact shoreline vegetation protection area or 35-foot deep strip of land along the shoreline. If a buffer is not present on a property, it is required prior to obtaining future building permits. Cost-share is available for buffer construction in certain instances. The Sawyer County Land and Water Division provides technical support including restoration advice and a listing of native vegetation, shrubs and trees that would be appropriate for a site.
- Lake Protection Grants are available to assist lake users, lake communities and local governments to undertake projects that protect and restore lakes and their ecosystems. This program is administered under Wisconsin Administrative Code NR 191, and typically provides up to 75% state cost sharing assistance up to \$200,000 per project. These projects may include watershed management projects, lake restoration, shoreland and wetland restoration, or any other projects that will protect or improve lakes.
- If a system is deemed not compliant with county code, the Sawyer County Conservation Department issues an “Order of Correction” letter requiring land owners to correct any identified issues with their septic systems within 12 months. A survey to determine septic system compliance was completed for properties around LCO in 2013.



- One option that should be considered to assure compliance with the TMDL is a memorandum of agreement (MOA) between WDNR and the cranberry bog owners in the LCO drainage area similar to the MOA that was developed in Massachusetts between state resource management agencies and the cranberry industry (Commonwealth of Massachusetts Department of Agricultural Resources, et al., 2009). In this agreement, the cranberry growers committed to the goal of closed systems (i.e. use of recirculation systems and holding ponds that do not discharge to surface waters). The agreement was developed in support of a TMDL for nutrients for a waterbody impacted by bog discharges.
- The Environmental Quality Incentive Program (EQIP) is a federal cost-share program administered by the Natural Resources Conservation Service (NRCS) that provides farmers with technical and financial assistance. Farmers receive flat rate payments for installing and implementing runoff management practices. Projects include terraces, waterways, diversions, and contour strips to manage agricultural waste, promote stream buffers, and control erosion on agricultural lands.
- USDA Farm Service Agency's (FSA) Conservation Reserve Program (CRP) is a voluntary program available to agricultural producers to help safeguard environmentally sensitive land. Producers enrolled in CRP plant long term, resource conserving covers to improve the quality of water, control soil erosion, and enhance wildlife habitat. In return, the FSA provides participants with rental payments and cost share assistance.
- Wisconsin's Managed Forest Law (MFL) is a landowner incentive program that encourages sustainable forestry on private woodlands in Wisconsin. Together with landowner objectives, the law incorporates timber harvesting, wildlife management, water quality and recreation to maintain a healthy and productive forest. To participate in the MFL program, landowners designate property as "Open" or "Closed" to public access for recreation, and commit to a 25 or 50 year sustainable forest management plan. The plan sets the schedule for specific forestry practices which landowners must complete. In return, MFL participants make a payment in lieu of regular property taxes plus a yield tax on harvested trees. Yield taxes go to the local municipality to help offset the annual property taxes that are deferred while properties are enrolled in the MFL.
- The Wisconsin Forest Landowner Grant Program (WFLGP) was created to encourage private forest landowners to manage their lands in a manner that benefits the forest resources and the people of the State. The WFLGP assists private landowners to protect and enhance their forested lands, prairies, and waters. The program allows qualified landowners to be reimbursed up to 50 percent of the eligible cost of eligible practices.

Public Participation

The LCO TMDL was developed with direct input from COLA and the LCOCD. The TMDL was presented at the COLA Annual Meeting on June 28, 2014.

A public review period was held for the TMDL from XX to XX. The review period was advertised by XX on XX. The advertisement provided information on the public comment period, including its dates and how to obtain copies of the public notice and draft TMDL. The news release, public notice, and draft TMDL were also placed on WDNR's website: http://dnr.wi.gov/org/water/wm/wqs/303d/Draft_TMDLs.html.

A total of XX letters of support...



6 Implementation

Water quality goals, wasteload allocations, and load allocations are established for LCO in this TMDL. This section presents an implementation plan that describes the steps to be taken and expected timelines needed to achieve the water quality goals.

Implementation will focus on six phosphorus loading sources:

1. Shoreline/ riparian landowners
2. In-lake management of Musky Bay sediments and curly leaf pondweed
3. Agriculture
4. Forest management practices
5. Small communities, rural residential, and new development
6. Cranberry bog discharges

Another key component of implementation discussed further in this section is continued monitoring and adaptive management based on new understanding and lessons learned.

COLA has prepared and adopted the “Lac Courte Oreilles Lake Management Plan” (Wilson, 2011; Appendix F), which lays out goals and implementation targets that address many of the phosphorus reduction implementation steps discussed .

LCO Shoreline/Riparian Landowners

Shoreline and riparian landowners have a direct impact on water quality based purely on proximity. These individuals play an important role in reducing phosphorus export to LCO through thoughtful decision making at a small scale. Oftentimes, shoreline and riparian landowners do not realize the negative impact that their everyday household management practices may have on water quality. Such practices may include misuse of fertilizers, inadequate buffers between developed land and surface waters, failing or damaged septic systems and runoff from impervious surfaces that they construct. The degree of impairment to water bodies as a result of these practices will vary depending upon the magnitude and frequency of each action. Shoreline areas in Wisconsin are protected to a certain degree by the enforcement of shoreline ordinances established at state and local levels. These rules limit shoreline and riparian landowners to specific building codes, vegetation management and possible detrimental activities within riparian areas. Small-scale changes in land use practices can have large impacts on overall water quality in LCO.

Several reduction strategies exist that are designed to attenuate the amount of phosphorus entering adjacent surface waters. Many of these strategies are cost-effective and small-scale.

- Installation/construction of shoreline buffers
- Reduction/elimination of fertilizer application
- Repair failing/damaged septic systems
- Installation of rain gutters along rooftops to limit soil erosion around buildings



- Erosion control measures
 - Plant trees/shrubs to stabilize shoreline & riparian areas, especially along steep slopes
 - Limit land clearing/grading near shorelines
- Increase infiltration
 - Remove/reduce impervious surfaces near shoreline/riparian areas
 - Gravel driveways/walk paths in place of pavement
 - Use of paving stones for walkways in place of concrete
 - Installation of rain gardens to absorb water runoff from buildings/houses and paved areas thereby promoting slow infiltration

Continued education of and outreach to shoreline residents will be conducted by COLA. In addition, COLA will work to implement the goal in the Lac Courte Oreilles Lake Management Plan (Wilson, 2011) to complete buffers on 100% of riparian land. Compliance with septic system regulations for system design, operation and maintenance is also expected to be 100%.

The following websites contain information on lakeshore ordinances and best management practices for shoreline and riparian landowners.

- [EPA's Lake Shoreland Protection Resources](#)
- [Wisconsin DNR Safeguarding Our Shorelands for the Future](#)
- [Minnesota DNR Shoreland Management Resources](#)
- [University of Minnesota - Extension Shoreland Best Management Practices \(BMPs\)](#)

In-Lake Management

In-lake management techniques will be applied to control curly leaf pondweed throughout the lake and sediment phosphorus release in Musky Bay. Curly leaf pondweed will be controlled with the ongoing management program sponsored by COLA. Methods for sequestering phosphorus in the sediments of Musky Bay will be evaluated. Consideration of the sediment response time to incoming load reductions will be given; depending on implementation timeframes, sediments in Musky Bay may equilibrate to reduced loading within an acceptable time period without the need for intensive control measures.

COLA will engage lake associations for Whitefish and Grindstone Lakes to promote watershed and lake management techniques for those waterbodies, including septic surveys, shoreline buffer surveys, and buffer installation. In addition, COLA will assist in the review of agricultural sources of phosphorus and to help promote implementation of BMPs.

Agriculture

Agriculture comprises approximately 4% of the land use in the LCO watershed. Significant improvements in agricultural practices, such as nutrient management, conservation tillage, and buffer strips, have provided opportunities for farmers to make changes that can reduce the amount of phosphorus leaving their lands and entering the adjacent waters. However, additional efforts should be continually assessed and implemented to reduce phosphorus loads to surface waters. Cropland and livestock operations, if not managed properly, can create conditions resulting in increased phosphorus entering surface waters. Some of the biggest factors affecting phosphorus export from agricultural lands include soil erosion, animal waste and overuse or improper timing of fertilizer applications.



Throughout much of the basin, agricultural production systems and practices have changed significantly over the past twenty years. This evolution is largely due to the development and utilization of best management practices with respect to agricultural operations. These practices include:

- Use of conservation tillage and no-till practices
- Construction and maintenance of sedimentation ponds
- Vegetative filter strips and field buffers among row crops
- Implementation of rotational grazing pastures
- Implementation of crop rotation
- Cover crops
- Nutrient management plans - proper use (i.e., amount) and timing of fertilizer (manure) applications
- Ditch management to mitigate phosphorus/sediment inputs to surface waters
- Proper containment and management of animal waste
- Vegetative filter strips near barnyards and milkhouses
- Exclusion of livestock from sensitive areas
- Installation of riparian buffers between crops/livestock areas and adjacent surface waters
 - Prevention of animal grazing in these areas
 - Plant trees/shrubs to stabilize banks thereby preventing erosion
- Retirement of cropland located in areas known to have a disproportionately high contribution to phosphorus export.
- Wetlands restoration.

The following sources contain an abundance of information regarding phosphorus reduction strategies and best management practices for the agricultural community.

- [Wisconsin Department of Agriculture Trade and Consumer Protection](#)
- [Discovery Farms](#)
- [University of Wisconsin Ag. Extension](#)

Forest Management Practices

Approximately 53% of the LCO watershed is forested. Forestry management activities can represent a significant phosphorus load contribution to surface waters. Increased phosphorus loadings from forestry are typically the result of accelerated erosion from land surface and riparian areas as well as increased terrestrial organic matter inputs directly to surface waters. There are numerous opportunities to reduce phosphorus inputs to waterways in forested areas. Careful planning of forest management activities and mindful consideration of potential water quality impacts during road construction, harvesting, and other management practices can significantly reduce phosphorus inputs to surface waters from forestry related activities. As with agriculture, phosphorus reduction strategies for forestry are known, but financial support is needed to identify, conduct outreach to, and provide technical assistance for forest managers within critical source areas.

State and national tax incentive programs and third party certification groups also provide opportunities for improved forestry practices:

- [Wisconsin Managed Forest Law Program](#)
- [Sustainable Forestry Initiative](#)
- [Forest Stewardship Council](#)
- [American Tree Farm System](#)
- [Wisconsin's Forestry BMPs for Water Quality](#)



Small Communities, Rural Residential, and New Development

Small communities, rural residential areas, and new development provide opportunities for reducing phosphorus loads in the basin. Development has the potential to significantly alter the hydrology of the landscape resulting in significant changes to the flow and volume of stormwater runoff. Impervious surfaces are widely distributed in urban environments leading to reduced rates of infiltration and increased opportunities for incorporation of phosphorus into stormwater runoff. Other factors that contribute to increased phosphorus loadings in developed areas:

- Overuse of fertilizers
 - Golf courses, commercial and private lawn care
- Pet/animal waste
- Lawn and yard waste (i.e., retention of leaves/grass on pavement, car washing)
- Sediment erosion/erosion from small construction sites
- Failing septic systems
- Road construction and maintenance activities

There are also many small-scale modifications to practices in developed environments that provide opportunities to reduce phosphorus loadings to surface waters. These include:

- Stormwater pollution prevention planning and implementation for small communities and towns
- Proper use of fertilizers or use of fertilizers with no phosphorus
- Proper disposal of pet waste
- Reduced impervious surfaces
- Installation of rain gardens/wetlands/retention basins that absorb excess runoff and promote ground infiltration
- Installation of rain gutters that control flow from rooftops thereby redirecting stormwater away from impervious surfaces
- Proper containment/prevention of sediment erosion
- Collection and disposal of lawn waste
- Inspection and proper maintenance of septic systems
- State of the Art BMPs for street and road construction, reconstruction, subdivision development, and redevelopment in small communities

The water resource education techniques needed to reduce runoff from urban and rural residential areas include:

- 1) Education, commercial advertising and social marketing to residents and other key audiences within the community to reduce widespread, small sources of phosphorus such as fertilizers and lawn waste.
- 2) Outreach and technical assistance to private landowners within the community to support implementation of targeted BMPs within critical source areas.
- 3) Training/Workshops for county and municipal staff, contractors and builders on how to reduce phosphorus from construction and development / redevelopment (both public and private), parks and public grounds maintenance, road work and other common practices.
- 4) Education, Training/Workshops and Technical Assistance for county and city elected and appointed officials to support the development and implementation of policies, ordinances, standards and practices that will reduce phosphorus loading.

The following resources provide additional guidance:

- [University of Wisconsin - Extension Home & Yard Publications](#)
- [University of Minnesota - Extension Lawn Care](#)
- [Clean Water Minnesota Yard Care](#)



Cranberry Bog Discharges

Best management practices (BMPs) for cranberry farming have been identified and the best available technology (BAT) economically available should be considered for surface waters receiving phosphorus loading from cranberry bog discharges. Some of these BMPs and BATs are being implemented in Massachusetts to help reduce phosphorus loading from cranberry bogs (Demoranville and Howes, 2005) and include:

- Use of recirculation systems or holding ponds to retain water;
- Avoid overuse of fertilizer;
- Avoid fertilizer application to waters that will exit the bogs; and
- Limit fertilizer applications prior to flooding events.

BMP practice guides for various elements of cranberry production are available from the UMass Cranberry Station, including a guide on nutrient management:

<http://www.umass.edu/cranberry/pubs/bmps.html>

Monitoring and Adaptive Management

Water quality monitoring will continue to be conducted annually by the LCOCD at the seven primary monitoring stations in LCO over the summer period. In addition, monitoring of tributary inflows will be conducted at Grindstone, Osprey, and Whitefish Creeks following the onset of implementation efforts. An efficient water quality monitoring program is essential for successful implementation. A comprehensive, well-planned monitoring program supports implementation by answering the following questions:

- *Where do we stand today and how much further do we have to go?*
- *Where should we prioritize our efforts?*
- *How effective are the implementation efforts and are refinements to the plan called for to improve efficiency?*
- *How will we know when we get there and if we continue to maintain our goals?*

It should be understood that the water quality goals, phosphorus loads, and needed reductions presented are estimates based on the best available science and continued state-of-the-art monitoring spanning over 10 years by LCOCD. Adaptive implementation is an approach that allows TMDL implementation to proceed in the face of uncertainties, by allowing for the implementation plan to be adjusted in response to information gained from future monitoring data. The adaptive implementation process begins with initial actions that have a relatively high degree of certainty associated with their water quality outcome. Future actions are then based on continued monitoring.



Blank page



7 References

Commonwealth of Massachusetts Department of Agricultural Resources and Commonwealth of Massachusetts Department of Environmental Protection and the Cape Cod Cranberry Growers' Association and Umass Cranberry Station. Memorandum of Agreement Regarding Development of Best Management Practices For Nutrient Application, Water Use And Return Flows. Dated May 6, 2009.

Courte Oreilles Lakes Association. 2014. Phosphorus Site-Specific Criteria Proposal for: Lac Courte Oreilles. June 18, 2014.

Demoranville C. and B. Howes. 2005. Phosphorus dynamics in cranberry production systems: developing the information required for the TMDL process for 303d water bodies receiving cranberry bog discharge. Prepared for the Massachusetts Department of Environmental Protection and the US Environmental Protection Agency Region 1.

<http://archives.lib.state.ma.us/bitstream/handle/2452/112824/ocm74723483.pdf?sequence=1>

Ernst, M. R., W. Frossard, and J. L. Mancini. 1994. Two Eutrophication Models Make the Grade. *Water Environment and Technology* 6 (11), pp 15-16.

Fitzpatrick, F.A, P.J. Garrison, S.A. Fitzgerald and J. F. Elder. 2003. Nutrient, Trace-Element, and Ecological History of Musky Bay, Lac Courte Oreilles, Wisconsin, as Inferred from Sediment Cores. United States Geological Survey Water-Resources Investigations Report 02–4225. Middleton, WI.

Heiskary, Steven A. and C. Bruce Wilson. 2005. Minnesota Lake Water Quality Assessment Report: Developing Nutrient Criteria. Third Edition. Minnesota Pollution Control Agency.

Heiskary, Steven and Bruce Wilson. 2008. Minnesota's Approach to Lake Nutrient Criteria Development. *Lake and Reservoir Management* 24:282-297, 2008

James, William F. 2013a. Sediment Characteristics and Diffusive Phosphorus Fluxes in Lac Courte Oreilles, Wisconsin. University of Wisconsin – Stout Sustainability Sciences Institute.

James, William F. 2013b. Sediment Characteristics and Diffusive Phosphorus Fluxes at Near-Shore Cranberry Bog Inlet Areas in Lac Courte Oreilles, Wisconsin. University of Wisconsin – Stout Sustainability Sciences Institute.

Lac Courte Oreilles Conservation Department (LCOCD). 2011. Quality Assurance Project Plan for 106 Water Quality Monitoring Project Lac Courte Oreilles Reservation

Hayward, Wisconsin. Revision 2 for Grant ID#I-00E05801 and I-00E57501.

McEnroe, B. M. and Gonzalez, P. (2003) Storm Duration and Antecedent Moisture Conditions for Flood Discharge Estimation. Report to Kansas Dept. of Transportation, Report No. K-TRAN: KU-02-4

Minnesota Pollution Control Agency and Wisconsin Department of Natural Resources (MPCA and WDNR). 2012. Lake St. Croix Nutrient Total Maximum Daily Load.

NOAA. 2014. Climate Data Online. National Climatic Data Center: National Oceanic and Atmospheric Administration. Available at: <http://www.ncdc.noaa.gov/cdo-web/#t=firstTabLink>. Accessed 16 February 2014.



Nordin, R.K. 1986. Nutrient water quality criteria for lakes in British Columbia. *Lake and Reservoir Management* 2:110-113.

Pratt, Frank. 2013. Loss of Beneficial Uses, Musky Bay, Lac Courte Oreilles.

Robertson, D.M., Rose, W.J., and Juckem, P.F., 2009, Water Quality and Hydrology in Whitefish (Bardon) Lake, Douglas County, Wisconsin, with Special Emphasis on Responses of an Oligotrophic Seepage Lake to Changes In Phosphorus Loading And Water Level: U.S. Geological Survey Scientific Investigations Report 2009–5089. http://pubs.usgs.gov/sir/2009/5089/pdf/sir2009-5089_web.pdf

United States Department of Agriculture (USDA).1986. Urban Hydrology for Small Watersheds. Technical Release 55 (TR-55) (Second Edition ed.). Natural Resources Conservation Service, Conservation Engineering Division.

Walker, W. W., 1985. Empirical Methods for Predicting Eutrophication in Impoundments; Report 3, Phase III: Model Refinements. Technical Report E-81-9, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Wilson, C. Bruce. 2010. Lac Courte Oreilles Economic Survey and Assessment. Prepared for the Wisconsin Department of Natural Resources under a Lake Management Grant to the Courte Oreilles Lakes Association.

Wilson, C.Bruce. 2011. Lac Courte Oreilles Lake Management Plan. http://www.cola-wi.org/docs/Lac_Courte_Oreilles_Lake_Management_Plan.pdf (Accessed on May 2, 2014).

Wisconsin Department of Natural Resources. (2013). Wisconsin 2014 Consolidated Assessment and Listing Methodology (WisCALM). 2014. Clean Water Act Section 305(b), 314, and 303(3) Integrated Reporting. September 2013. <http://dnr.wi.gov/topic/surfacewater/documents/2014/2014WisCALM.pdf>

Wisconsin Department of Natural Resources (WDNR). 2014. Metadata Attribute Reclassification. 21 March 2014. Available at: ftp://dnrftp01.wi.gov/geodata/hydro_va_24k/WDNR_Hydro_VA_metadata/metadataAttributeReclassification.pdf. Accessed 1 April 2014.



Appendix A



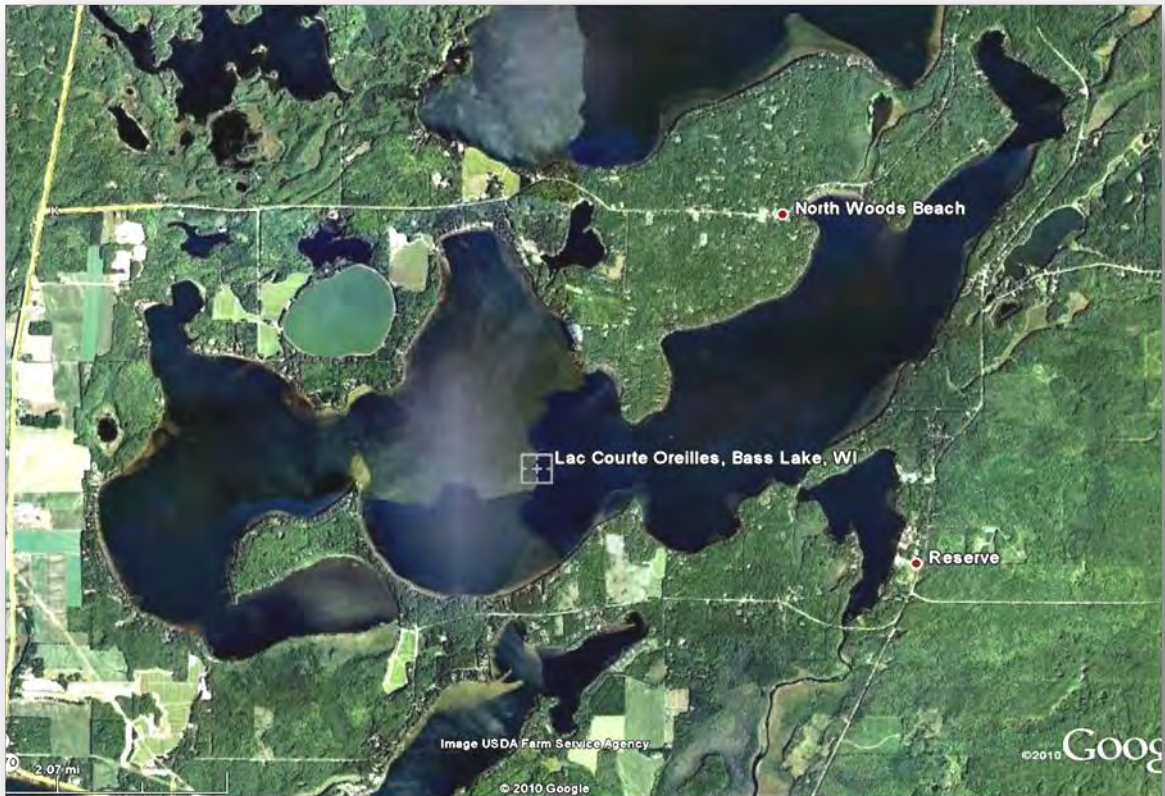
Blank Page



Lac Courte Oreilles

Economic Survey and Assessment

C. Bruce Wilson
November 28, 2010



“Welcome to the Hayward Area

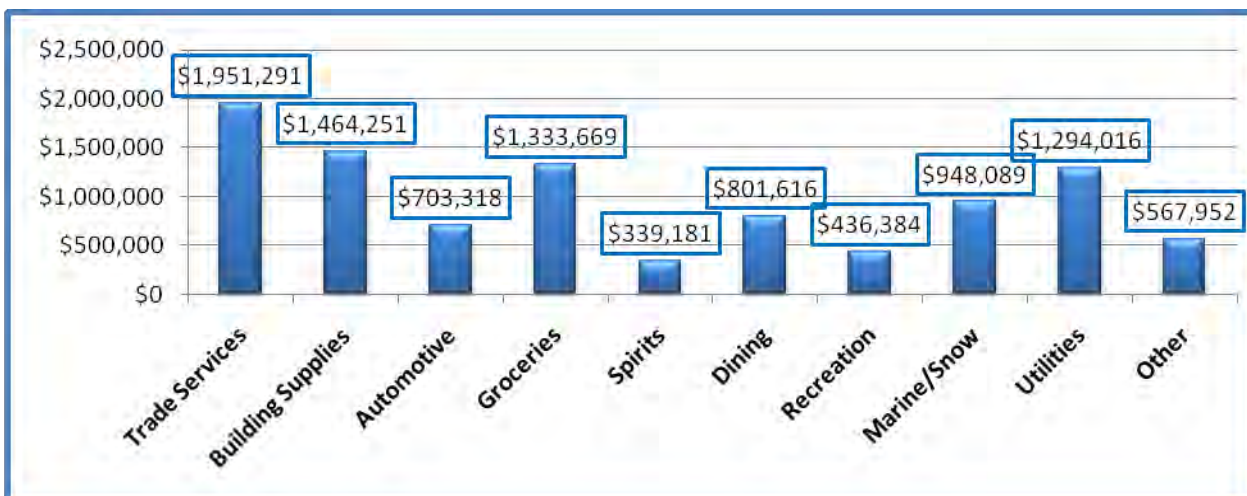
The Hayward Area Chamber of Commerce would like to invite you to take a walk at a slower pace and enjoy our wonderful Hayward Lakes region of Northern Wisconsin. Come to the Hayward, Wisconsin Area where you'll find a community rich in history, culture, recreation and commerce. *After all, thousands of vacationers and second home owners return every year because they just can't get enough of the area's Northwood charm.* With crystal clear lakes for water sports and fishing, and miles of trails for riding snowmobiles, ATVs, cross-country skiing, hiking, and off-road/on-road bicycling, this area is buzzing with activity year-round. The Hayward, Wisconsin Area also has a unique selection of golf courses that will make a memory for any skill level golfer! ... There's no time like the present to explore one of Wisconsin's most popular - vacation and relocation destinations.” (<http://www.haywardareachamber.com/>, October 19, 2010)

Executive Summary and Overview

Lac Courte Oreilles (LCO) is a popular and regionally recognized Hayward Area destination receiving an estimated 84,000 visitor days per year from full-time LCO residents + seasonal LCO residents (second home property owners) + their LCO guests - estimated from mail-in surveys sent to 650 LCO residents. LCO Residents and their guests purchase a wide variety of goods and services with estimated LCO resident annual expenditures, varying from about \$2 million dollars for trade services (plumbing, electricians, carpenters etc), \$1.5 million for building supplies, \$1.3 million for groceries and utilities, \$948 thousand dollars for marine/snowmobile, \$801 thousand for

dining out, and \$703 thousand for automotive. Survey responses were summed by category from the 219 respondents and then extrapolated to 650 LCO residents. In total, estimated LCO resident total 2009 expenditures were ~\$9.8 million. Using a range of multipliers, the total effects of these expenditures in the LCO region was approximated to be about \$ 10.8 million to \$14.8 million annually. These values represent about 9% of total Sawyer County travel and tourism revenue noted in 2008. Travel and tourism, referred to as one of the three pillars of Wisconsin industry along with agriculture and manufacturing, was estimated by the Wisconsin Department of Tourism to be about \$12 billion in 2009 and responsible for about 300,000 jobs (Davidson-Peterson Associates, 2010).

Figure 1: LCO Resident Total Estimated Annual Expenditures by Category



Property Value and Tax

LCO, Little LCO, Grindstone and Whitefish Lakes associated properties had a combined 2009 estimated fair market value of ~ \$590 million with taxes totaling ~ \$5.1 million. Lac Courte Oreille's associated properties with a total estimated fair market value of ~\$331 million and total taxes of ~ \$2.9 million, exceeded the total of other three lakes' combined.

Land values and taxes for properties associated with two of three cranberry growing operations adjacent to LCO (includes values for residential, forest, forest productive, agriculture, agriculture forest, and undeveloped land classifications) were estimated from the same records, (Table 1), to be about \$1.8 million estimated fair market total value with annual taxes of about \$15,000.

„Northwood Charm“ as a Regional Product

From a business sense, the „Northwood Charm“ is a significant „product“ of the region. Competing for and sustaining future travel and tourism will be dependent upon maintaining the quality of the product, otherwise discretionary travel dollars may be spent elsewhere. And in a long-term business sense, this will require re-investing in forest and restoring and protecting the water assets that cover 84% of the lake's watershed. The intensity of land uses and future development pressures will require additional proactive operation and maintenance rather than an „it will take care of itself approach“.

Key challenges include maintaining forests & waters in an increasingly variable climate with droughts, fires, wet periods, intense storms (damage, erosion and shock loads to lakes and streams), non-native species infestations (lakes, wetlands and forests) and longer growing seasons. A balance must be achieved between limiting the amount of pollutants flowing into waters and water use conflicts so the lakes stay healthy and maintain present beneficial uses. This will mean enforcement of existing land use ordinances and minimizing variances for nonconforming structures and practices (Losing our lakes: Part 1. Rules skirted and lakes under attack, Minneapolis Star Tribune, July 6, 2010) and adopting new low impact development ordinances to treat stormwater runoff on site. Stormwater volume control standards have the most promise of minimizing stormwater runoff by requiring new developments to treat runoff from impervious surfaces on-site via infiltration, storage, or reuse. Continued installation, operation and maintenance of agricultural and forestry Best Management Practices (BMPs) by producers will be very important.

As land is converted from forest into intensive urban or agricultural land uses, there will be increased loss of nutrients and sediments to the lakes. For comparison, present day average watershed total phosphorus in runoff typically contains very low levels (on the order of 10-40 parts per billion) versus much higher concentrations in agriculture and urban runoff (on the order of 150 – 600 parts per billion). The cumulative effects of the pounds of phosphorus reaching LCO is significant as each part per billion increase in LCO average summer total phosphorus can result in a loss of about one-half foot of average summer water clarity, particularly in the east and central LCO bays.

Report Sections

This report begins to quantify the importance of revenue generated as a result of full-time and seasonal LCO residents and their related visitor tourism dollars brought into the area from other states and regions. The assessment consists of four sections: 1) Economic Values of Water Quality, 2) Lac Courte Oreilles Water Resources, 3) LCO Area Demographic and Economic Overview and 4) Lac Courte Oreilles Economic Survey Summary.

1. Economic Values of Water Quality

There are considerable economic implications of „contingent values“ or willingness to pay for beautiful hills, lakes and forest settings and solitude. However, there are no economic assessment methods for defining economic returns associated with cultural, spiritual, and aesthetic values. Yet these values are significant, particularly for the Lac Courte Oreilles Band of Ojibwe - as well as the Chamber of Commerce, LCO residents and visitors.

The following key studies in Wisconsin, Maine and Minnesota have investigated the linkage of property value to water quality:

- What is the Value of a Clean and Healthy Lake to a Local Community, prepared for the Delevan Lake Improvement Association (Eiswerth, etal, 2005);
- Lakeshore Property Values and Water Quality: Evidence from Property Sales in the Mississippi Headwaters Region (Krysel etal, 2003);
- Additions and Corrections to the Economic Portion of the Environmental Impact Statement, Bemidji Wastewater Treatment System, Beltrami County, MN, (Larson (1980); and
- Water Quality Affects Property Prices: A Case Study of Selected Main Lakes, (Michael etal, 1996.)

Water quality is a non-market place value that is not bought and sold outright. Rather, it is linked to recreational activities such as fishing, boating and property values. A review of the linkage of water quality to fisheries, swimming and user perceptions is provided separately by Wilson (2010). One of the primary conclusions of these studies is that lake water clarity is very important in explaining lakeshore property prices. Lakeshore buyers will pay more for properties on lakes with better water quality based on summer water clarity. The converse was found to also be true, lake shore property values will decline with degraded water quality. For example, expected price changes for northern Minnesota lakes resulting from a 3.3 foot (1 meter) increase or decrease in clarity were extraordinary – 10's of thousands to millions of dollars per lake depending on the lake's size. The authors concluded that the management of lake quality was extremely important to maintaining the natural and economic assets of northern Minnesota (Krysel et al., 2003).

The University of Wisconsin-Whitewater (Eiswerth et al, 2005) found that the value of Delavan Lake real estate rose faster than property on nearby lakes in Walworth County subsequent to a \$7 million lake restoration project. Delavan's lakeshore property values jumped 352% between 1987 and 1995. The study further found that households in the Delavan area spent an estimated \$52.6 million annually. The same study surveyed boat launches and found that an additional \$9.4 million was generated annually from visitors.

Additional studies conducted in Maine (Michael et al, 1996) reveal that, for a town with 60% lakefront property, a decline of one meter (3.3 feet) of water clarity could result in a loss of 5% of the total property value for lakeshore property; which would eventually be reflected in higher tax rates to support the same level of local services. Therefore, although property taxes on lakeshore property would decrease, actual taxes paid by non-shoreline owners would rise by 5%.

A 1980 study by Larson (1980) concluded that "recreationists will seek alternative bodies of water, or reduce the level of their activity in response to perceived water pollution; algae is often mentioned as an indicator of pollution by recreationists". Larson, (1980) also noted that "studies indicate a strong connection between the environmental quality in the area and satisfaction gained by visitors" as a part of the Lake Bemidji, MN wastewater effluent limit adoption of 0.3 mg P/L. In this case, the City of Bemidji acknowledged the significance of excellent water quality in order to compete for tourism and travel to the land of „Paul Bunyan “.

2. Lac Courte Oreilles Water Resources



LCO, located in Sawyer County, is one of Wisconsin's largest natural lakes with a surface area of 5,039 acres and represents about 9% of the County's lake acreage. The lake has several identified bays, which for the purposes of this summary, are identified as east, central, west, and Musky. In total, LCO stretches approximately six and one-half miles in a predominantly southwest to northeast orientation with an overall mean depth of about 34 feet, a maximum depth of 90 feet and a shoreline length of 25.4 miles. Two of the lake's main tributaries, Grindstone and Osprey Creeks enter on the east bay along with Spring Creek on the south side. Whitefish Lake discharges into the southern side of central bay. The lake outlets from the east bay through a short passage to Little Lac Courte Oreilles, then to the Billy Boy Flowage, the Couderay River and then the Chippewa River. Hence, most water flows into and out of LCO occur through the east bay - except for bay-to-bay wind mixing. With much less water runoff reaching the central and west bays, they have longer water residence times that will tend to make them more sensitive to runoff from direct drainage areas (storm shock-loads, shore land development, cranberry operations, agriculture, and urban centers). Ultimately Lac Courte Oreilles flows into the Mississippi River at Lake Pepin.

The LCO watershed at the lake outlet, covers 68,990 acres and includes other significant Wisconsin natural lakes such as Round Lake (3,054 acres) and Grindstone Lake (3,116 acres) that drain into the east bay; and (2) Sand Lake (928 acres) and Whitefish Lake (786 acres) that drain into the central bay (Wilson, 2010). The eastern ~half of the lake is located in the Lac Courte Oreilles Indian Reservation. The lake has an abundance of sport fisheries and is a popular fishing and recreational area drawing LCO property owners and visitors from Wisconsin, Minnesota, Illinois and other states.

In the past, Musky Bay, located in the southwestern portion of LCO, supported fisheries and the native (legacy) crop, wild rice. Now, the nuisance exotic aquatic Curly Leaf Pondweed and algal

masses can cover significant portions of Musky Bay. The US Geological Survey (Fitzpatrick et al, 2003) collected and assessed sediment cores from Musky Bay, Lac Courte Oreilles, and from surrounding areas and determined the water quality of Musky Bay has degraded the last ~25 years with increased growth of aquatic plants and the onset of floating algal mats. Courte Oreilles Lakes Association (COLA), the LCO Tribe, Sawyer County and the Wisconsin Department of Natural Resources (WDNR) have been working closely to control Musky Bay's Curly Leaf Pondweed infestation via chemical treatments. However, Curly Leaf Pondweed has spread beyond Musky Bay to other parts of Lac Courte Oreilles.

3. LCO Area Demographic and Economic Overview

Lac Courte Oreilles Area Lakes Property Values and Taxes

Sawyer County provided an excel spreadsheet summary pertaining to properties around Lac Courte Oreilles, Grindstone, Whitefish, and Sand Lakes in response to a request for information (personal communication from Mike Coleson to Bruce Wilson July 6, 2009). This data was parsed by Water Body Name (wbnname), Estimated Fair Market Value Improvements (structures) (efmvl), Estimated Fair Market Value: General Land (efmvL), Estimated Fair Market Value: Forest Land (efmvF), Estimated Fair Market Value: Total or (efmvTot), and Taxes Due. Summary results are reported by lake in Table 1.

Table 1. Area Lake Property Values and Tax Summary*

Lake	Estimated Fair Market Value Structures	Estimated Fair Market Value Land	Estimated Fair Market Value Forest	Estimated Fair Market Value Total	Taxes	# Prop
Lac Courte Oreilles	\$97,686,885	\$232,118,085	\$1,312,085	\$331,115,485	\$2,857,856	785
Little Courte Oreilles	\$5,092,600	\$8,186,900	\$0	\$13,279,500	\$110,570	55
Grindstone Lake	\$40,398,700	\$94,529,200	\$0	\$134,927,900	\$1,152,688	351
Whitefish Lake	\$36,887,300	\$72,257,200	\$0	\$109,144,500	\$959,493	288
Lakes" Total	\$180,065,485	\$407,091,385	\$1,312,085	\$588,467,385	\$5,080,607	1,479
Values associated with two cranberry growers on LCO	\$258,900	\$1,493,400	\$0	\$1,752,300	\$14,745	

*Spreadsheet summary of data provided by Sawyer County.

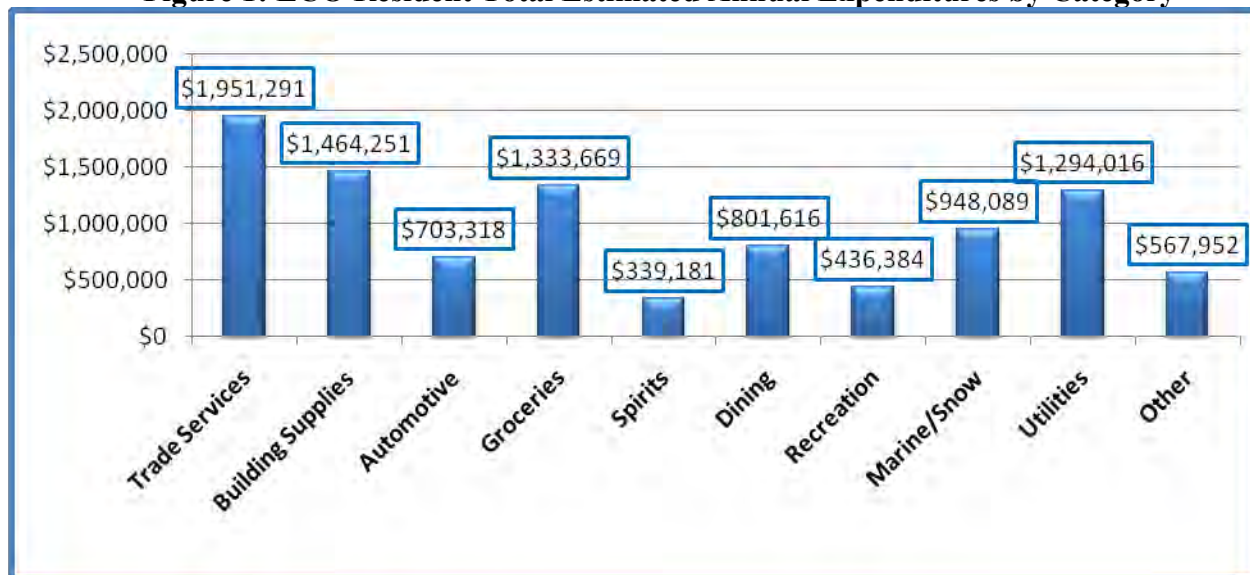
LCO, Little Lac Courte Oreilles, Grindstone and Whitefish Lakes had a combined 2009 estimated fair market value (efmvTl) of ~ \$590 million with property taxes totaling ~ \$5.1 million. LCO's

total estimated fair market value of ~\$331 million and total taxes ~ \$2.9million, exceeded the combined totals from the other three lakes.

Land values and taxes for properties associated with two of three cranberry growers adjacent to Lac Courte Oreilles were estimated for all land classifications: residential, forest, forest productive, agriculture, agriculture forest, and undeveloped. Total values by estimated fair market class were summarized with the lake data in Table 1 to be about \$1.8 million estimated fair market total value with annual taxes of about \$14,745. The total of Lac Courte Oreilles related properties in 2009 had estimated fair market value that was about 189 times the values associated with two of three cranberry growers discharging to LCO.

Expenditures from 219 survey respondents totaled \$3.3 million and when translated to the entire LCO population (650 residents) was estimated to be about \$9.8 million. Estimating the effects of these expenditures in the region was generally approximated to reflect uncertainties using a range of output multipliers of 1.1 to 1.5 with resulting estimate totals of \$ 10.8 million to \$14.8 million annually in Sawyer County.

Figure 1: LCO Resident Total Estimated Annual Expenditures by Category



The reported mean expenditures per LCO household were \$15,939 with about 98% of the survey respondents indicating they shop in Hayward and 67% shop in Stone Lake.

4. Area (Sawyer County) Demographic and Economic Summary

Table 2: Sawyer County Regional Demographic Summary

Population Data	Sawyer County
Population, 2008 estimate	17,117
Population, percent change, April 1, 2000 to July 1, 2008	5.7%
Population estimates base (April 1) 2000	16,197
Persons under 5 years old, percent, 2008	5.9%
Persons under 18 years old, percent, 2008	21.5%
Persons 65 years old and over, percent, 2008	19.7%

http://www.city-data.com/county/Sawyer_County-WI.html#ixzz13Eohz51X

Sawyer County covers an area of about 1256 square miles including about 56,183 acres of lakes. The total 2008 population was estimated to be 17,117 which was an increase of about 1,000 people from the 2000 census totals (5.7% growth as seen in Table 2). Population density is quite low or about 13 people per square mile. Median household income in 2008 was about \$47,313 (Table 3) with about 12.3% living below the poverty level and an unemployment rate noted to be about 10.6% in early 2010. The largest economic sectors are Government, Education, Food Services, and Amusement, Gambling and Recreation (Anonymous, 2010 City Data.Com).

Sawyer County's Comprehensive Plan (Northwest Regional Development Commission, 2010) was reviewed for indicator areas to approximate urban growth rates projections from 2000 to 2030. LCO is located in Bass Lake and Sand Lake Townships. By the year 2030, Bass Lake is projected to grow about 34% in population and about 55% in the number of households (about 297 additional households) while Sand Lake has a lower growth projection rate of 13% with a 30% increase in the number of households.

Table 3: Median Family Income, Sawyer County, Wisconsin*

Growth Estimate	Value	Growth
2013 Median Family Income	\$52,693	11.4%
2008 Median Family Income	\$47,313	21.8%
2000 Median Family Income	\$38,845	
2013 Median Household Income	\$46,133	16.4%
2008 Median Household Income	\$39,646	22.7%
2000 Median Household Income	\$32,305	

* Data from City.com, 2010.

Sawyer County: Agriculture

The majority of Sawyer County farms are operated by family or an individual who on average, work about 235 acres. The average value of agricultural products sold is about \$54,000 with livestock, poultry and associated products accounting for the majority agricultural products (53%).

Corn used for grain covered about 3,800 harvested acres with soybeans about 400 acres (City Data, 2010). Three operating cranberry industrial sites were noted in Sawyer County and cover about 161 acres and discharge into Lac Courte Oreilles. Annual cranberry production costs per acre have been estimated on the order of \$8,335 (Wisconsin State Cranberry Growers Association, 2010) with annual yields of about 243 barrels per acre (Anonymous, 2010). Annual revenue from all three cranberry operations is very approximately 161 acres x 243 barrels/acre x \$51 to \$65 per barrel (Wisconsin Cranberry Growers Association, 2010; National Agricultural Statistics Service USDA, 2010) or about \$ 2.0 - 2.5 million per year.

4. Lac Courte Oreilles Economic Survey Summary

COLA has focused on efforts to reduce pollution particularly phosphorus pollution, protect and restore critical habitat, research water quality issues and protect the water quality of the lake. COLA received a lake management planning grant from the Wisconsin Department of Natural Resources. This survey and report were developed as part of the grant in order to better understand the regional economic significance of Lac Courte Oreilles.

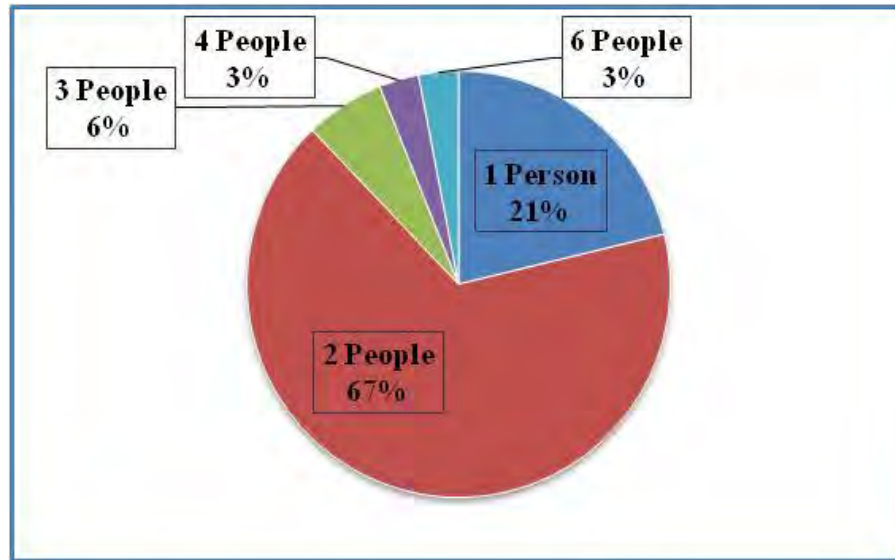
There were 650 mail-in surveys sent to LCO residents in early July, 2010 with a final submittal deadline of August 31, 2010. The 16 question survey was constructed to obtain both demographic (number of full time and seasonal residents plus visitor days) and economic (expenditures) data. Residents were also asked questions pertaining to their perceptions of water quality and if water quality would influence their intent in maintaining future lake property ownership

As stated previously, the survey employed a mail-in questionnaire. There are many advantages to mail surveys; they are relatively inexpensive to administer and use a format that includes both open-ended and multiple choice responses. But, there are some disadvantages as well; one disadvantage is that the response rates from mail surveys can be low and an appropriate number of responses must be received in order to statistically valid. Missing responses were evaluated as blanks in the final calculations. For example, 5 % (11 of the 219) of the respondents did not include expenditure data. Hence, mail-in surveys likely under-predict true economic impact. A total of 219 responses (~ 34 %) were tabulated in this analysis, allowing for late responses through late October, and therefore provide good estimates (e.g. a 95% confidence level) and relatively small margins of error with generally less than +/- 5 percentage points per question). All data was tabulated in Excel spreadsheet by question with average and percent of total values generally reported.

Demographics

(Q1) Full Time Residency: Survey respondents were asked, on average, how many people occupied the residence year-round. This information helps to assess the number of residents that permanently occupy their property year-round and are eligible to participate in local elections. There were 33 out of 219 responses (about 15% of the total) identified as full-time households with a total of 194 survey respondent household members. These respondents indicated that the about 67% of homes contained 2 occupants and year round residents were distributed around LCO.

Figure 1: Year-Round Residences



(Q2) Seasonal Residency: The vast majority (85%) of the survey respondents were seasonal (second home) residents with an average of four-persons per household. Respondents were asked to state the approximate number of days anyone in the household occupied the property in the past year, (by growing and cold seasons), how many people occupied the household during the year and the state where they maintained primary residence.

The average survey respondent time spent in the LCO area during the growing season (May to October) was 77 days (Table 5). In other words, seasonal residents spend over half of the summer at the lake and allows for a reasonably long time frame for observing summer water quality conditions. 51% of the survey respondents indicated that they occupied their residence during the cold season (November-April) with an average stay of 24 days. About 11% of survey respondents indicated that they are planning permanent residency on LCO at some point in the future.

Table 5: Seasonal Respondent Occupancy Summary

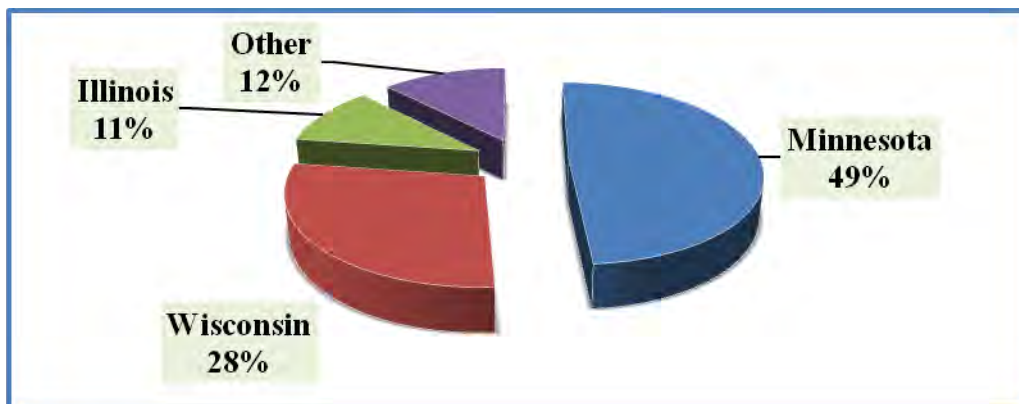
	Number of Days During Growing Season	Number of Days During Cold Season	Number of Occupants
Mean	77	23.9	4.1
Median	60	20	3
75 th %	108	30	5
25 th %	35	10	2

Total Estimated LCO Population. The survey respondents accounted for a seasonal (second home) lake population of about 16,670 resident days, a full time population of about 22,750 resident days and 3,750 days from visitors. Extrapolating that to the entire lake, it was estimated to be a total annual of 49,677 seasonal resident days + 22,750 full-time resident days and 11,181 visitor

days. All together this gives an estimated total LCO population of about 84,000 days with an estimated winter population of about 7,696 days.

(Q2.d) Seasonal Resident Originating State According to the survey results, most seasonal respondents indicated they are originating from Wisconsin (28%) and adjacent states most commonly identified were Minnesota (49%) and Illinois (11%) (see Figure 2). Also noted were primary residences in Iowa, Ohio, Florida, Kentucky, Arizona, Mexico, Kansas, Georgia and Hawaii.

Figure 2: LCO Ownership Primary Residency



Q7. Structure Size and Lakeshore Frontage: Survey respondents reported an average structure size was 1,911 square feet with an average lakeshore frontage of about 211 feet (Table 6).

Table 6: Approximate Structure Size and Lakeshore Frontage

	Structure Size (ft ²)	Lake Frontage (ft)
Response %	90 %	95%
Mean	1,911	211
Median	1,700	120
75th %	2,500	200
25th %	1,000	100

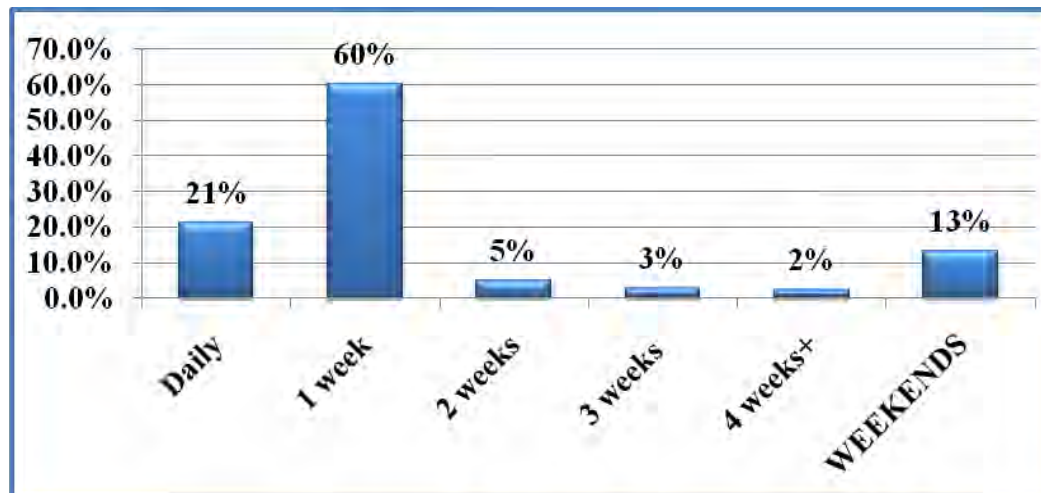
Q9 Approximate Number of Visiting Guests: Survey respondents were asked to provide approximate numbers of guests visiting their property per year and the average length of guest visit. About 34% of respondents indicated that, on average, they had between 10 and 20 visitors per year while 16 % of the respondents had 30 or more visitors per year (Figure 3).

Figure 3: Visitors per Resident Property per Year



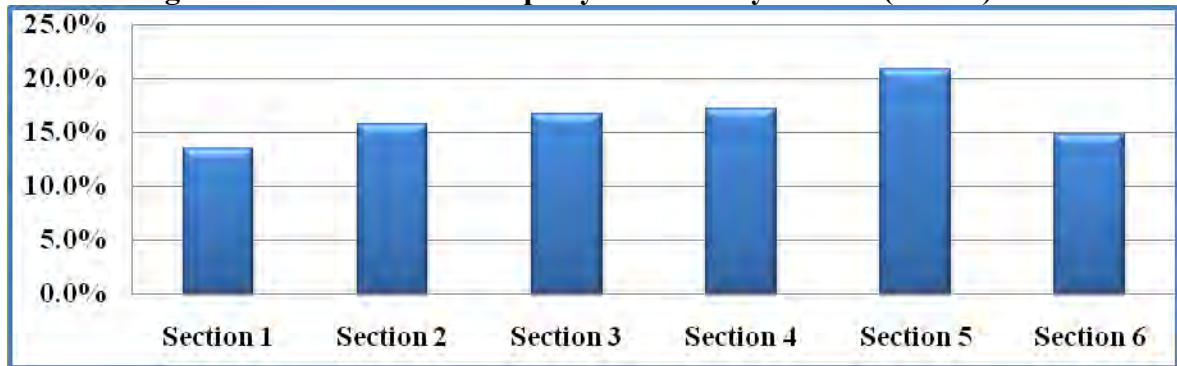
(Q 10) Average Guest Visit Duration. As noted above, LCO residents bring a large number of guests per year to the LCO area. Most survey respondents reported guests staying a day, a weekend or for one week - with 60% of respondents indicating the average visitor stay was one week (Figure 4). Visitor expenditures were not tabulated as a part of this survey but with an estimated 11,181 visiting days per year to LCO, their expenditures are likely substantial.

Figure 4: Visiting Period per LCO Resident Property
Average LCO Resident Visitor Stay (days)



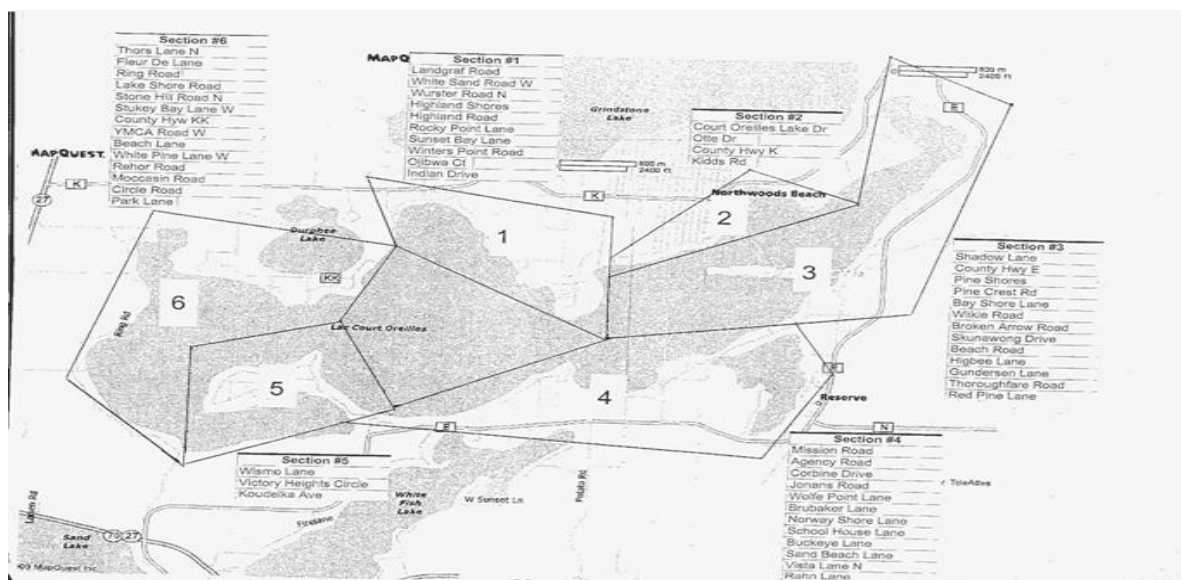
(Q3) LCO Residence Location: Survey respondents were asked to identify the lake section location for their residence. In general, a relatively similar response rate (e.g. 15%) was received from Sections 2, 3, 4 and 6; with slightly more from Section 5 (Victory Heights) and slightly less from Section 1 (north central bay) (Figure 5).

Figure 5: LCO Resident Property Location by Section (N=215)



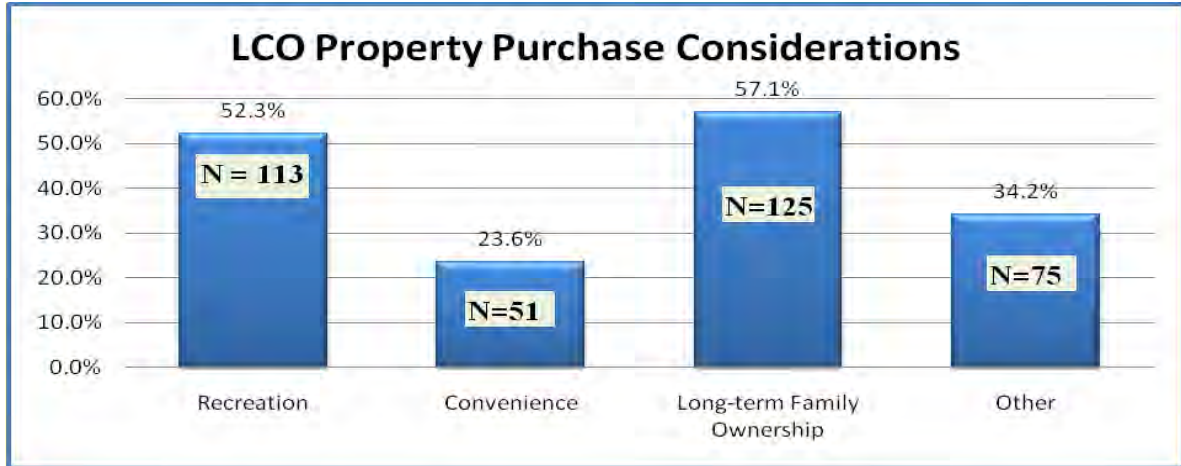
LCO Lake Areas (Sections), 1=N. Central Bay; 2=N. East Bay; 3=East Bay; 4=S East + Central Bays; 5= Victory Heights; 6= West Bay

Figure 5a. LCO Resident Location Sections



(Q4) Location Preference Factors: Survey respondents were asked the purpose for choosing their LCO section location with more than one response allowed. Respondents were given a choice of recreational activities, convenience (proximity to city shops, access roads etc.), long-term family ownership and an opportunity to write-in their own response. Some write-in comments included the setting and view, large lake and lakeshore appeal, and opportunity to purchase. About 57% of responses indicated Long-Term Family Ownership, 52% indicated Recreation, with 34% other, and 24% Convenient Location (Figure 6).

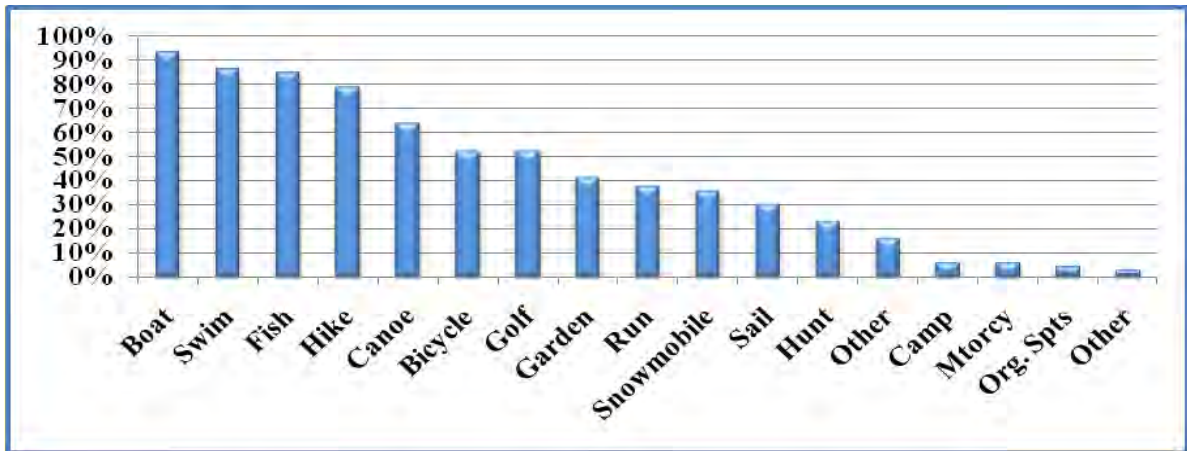
Figure 6: Property Purchase Considerations



(Q8) Recreational Activities: Survey respondents were asked which recreation activities they and their families pursue while in the LCO area. This question was designed to estimate the impact of environmental resources on property selection as well as get a sense of potential economic indicators associated with these activities.

Survey respondents overwhelmingly participate in water-related recreational activities with boating most often indicated (93%). This activity has associated expenses such as gas, oil, miscellaneous marine repairs and parts etc. that survey responses, when extrapolated for LCO, amounted to ~ \$948 thousand per year to the Sawyer County economy. Respondents also favored fishing (85%) swimming (86%), hike/walk (79 %) and canoe/kayak (63%) as indicated in Figure 7. 36% of survey respondents also enjoy winter activities such as snowmobiling. The survey did not specifically identify ice-fishing, but it is possible respondents included both summer and winter as fishing. Hunting was also noted by about 24% of survey respondents. Under the “other” category, some survey respondents wrote in comments that included cross country skiing and snowshoeing. Hence, LCO resident activities span all four seasons with year-round expenditures going into the regional economy.

Figure 7: LCO Activity Participation



Q 12. LCO Resident Expenditures. Survey respondents were asked to estimate total expenditures for several categories for the past year, including only expenditures made in LCO/Sawyer County area and not to include expenditures for items bought outside and then consumed in the area.

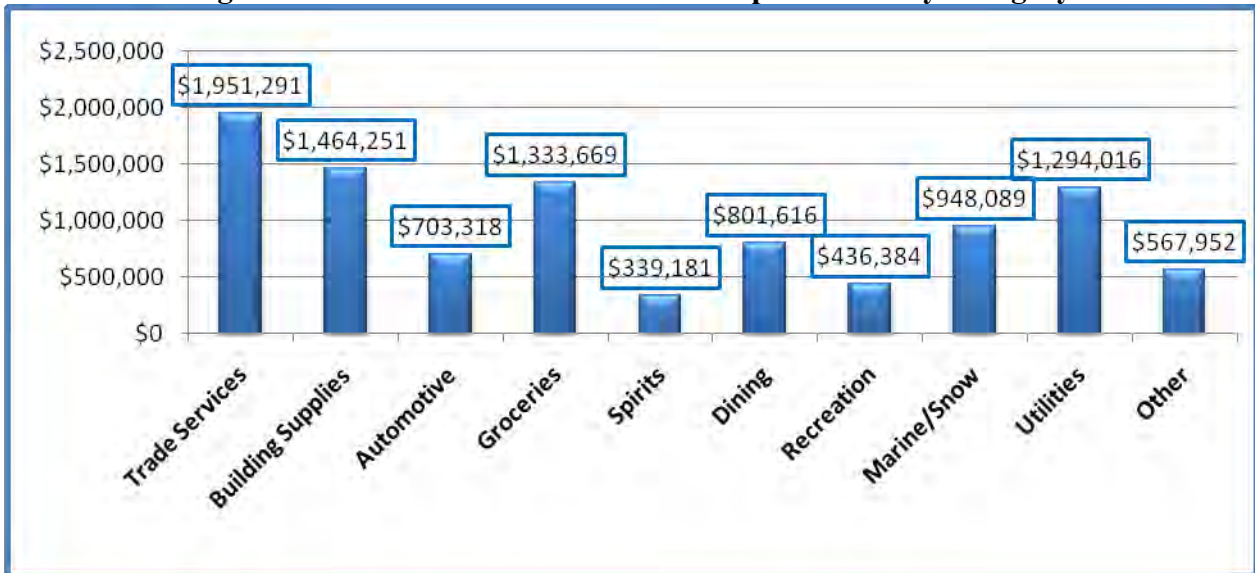
While recreational activities span all four seasons, summer activities dominate the recreational list. Typically, summer expenditures amount to 60% to 90% of annual expenditures. Average reported total expenditures per respondent were tabulated to be about \$15,939 per year. The largest expenditures were for trade services (plumbers, electricians, carpenters, masonry, landscaping, roofing, paving, cooling/heating) that averaged \$4,009 per year. Building supplies (hardware, lumber, concrete, etc.) was the next highest value averaging about \$3,122 per year per respondent. Groceries averaged about \$2,258 with Utilities averaging \$2,169 per year and per respondent also reported.

Table 7: Average Annual Reported LCO Resident Expenditures by Category

Category	Mean
Total Annual Average	\$15,939
Trade Services	\$4,009
Building Supplies	\$3,122
Groceries	\$2,258
Utilities	\$2,169
Marine/Snowmobile	\$2,115
Dining Out	\$1,337
Automotive	\$1,274
Other	\$1,106
Recreation	\$817
Spirits, Wine, Beer	\$657

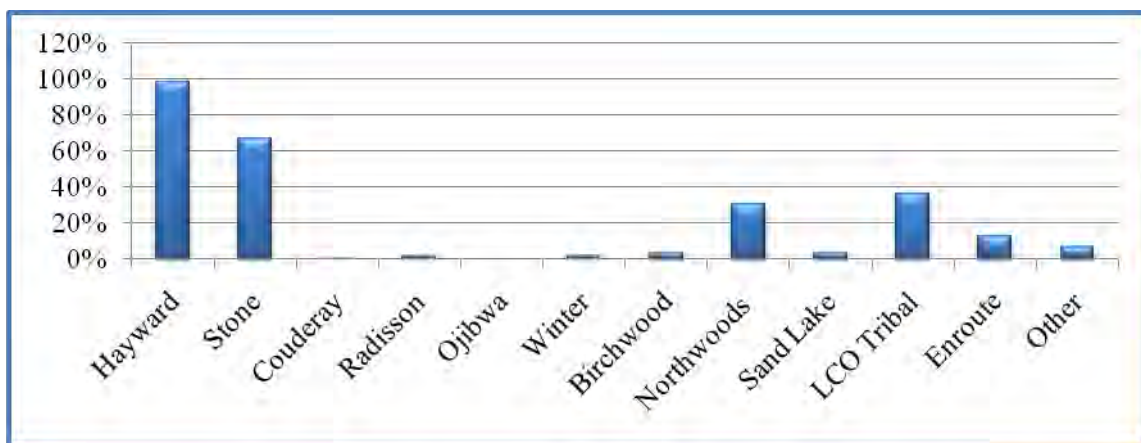
Tabulated survey responses for 219 LCO residents expenditures totaled \$3,315,245 (not including real-estate purchases) which when translated to the entire LCO population, was estimated to be about \$9,839,768. Total economic impact to the Sawyer County area was estimated to range from \$10.8 million to \$14.8 million using regional multipliers of 1.1 and 1.5. Regional multipliers are used to estimate the ripple effect of dollars in a region. For example, dollars spent at a restaurant pay salaries and suppliers who in turn spend dollars at other local businesses.

Figure 8. LCO Resident Total Annual Expenditures by Category



(Q13) Local Shopping Preferences: Survey respondents were asked where they shopped while in Sawyer County. They were also asked to estimate the percentage of shopping in each community. 98% of the survey respondents selected Hayward, 67% selected Stone Lake and 36% selected the LCO Tribal Stores (Figure 9).

Figure 9. LCO Resident Shopping Preferences



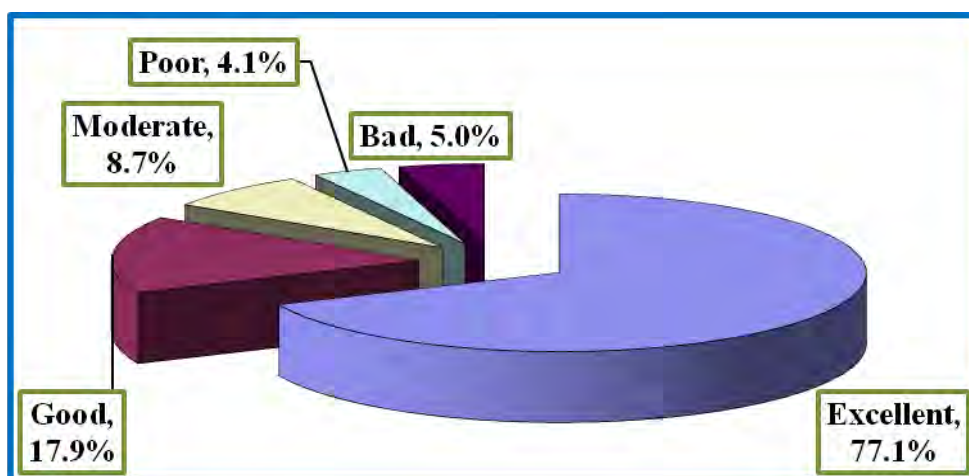
(Q11) Charitable Donations: Survey respondents were asked if they contribute to Lac Courte Oreilles area charities. 71 % of respondents said they donate to local LCO area charities with a median donation was \$100 per year. The largest annual donation was \$ 5,000 and the mean annual donations were \$540.00 with about \$64,000 in donations reported by survey respondents (Figure 10).

Figure 10: LCO Resident Local Charitable Contributions



(Q5) Resident Water Quality Perceptions: Survey respondents were asked to identify their perception of the water quality condition of their LCO bay location at the time of purchase (Figure 11). They were also asked for the approximate date of purchase to help establish a baseline span for an historical assessment of perceived water quality conditions in LCO. 77% of respondents (N=168) reported that the water quality near their property was excellent at the time of purchase with an established median ownership of 32 years (N=80). Two respondents confirmed a baseline for family ownership of their property of over one hundred years. About 5 % of respondents identified their water quality as „bad“ at the time of purchase with baseline dates of 2005 and 2010.

**Figure 11: Perceived Water Quality in Owner's LCO Bay at Purchase
(Median date of purchase = 1978 or ~ 32 years baseline)**



(Q6) Water Quality Perceptions: Survey respondents were then asked if the water quality was the same today as it was at the time of purchase and if it is better or worse today. 66% of 219 responses said the water quality was not the same with 59% stating the water quality was worse

today (Figure 12). Some write-in comments included: less clarity, more aquatic plants, no frogs, more algae, wildlife all but gone, more weeds, no clams, swimmer's itch, slime, and water not as clear. 3% of respondents believed the water quality had improved in their LCO section. Water quality degradation was perceived in all LCO sections.

Figure 12: Perceived Water Quality Same Since Purchase

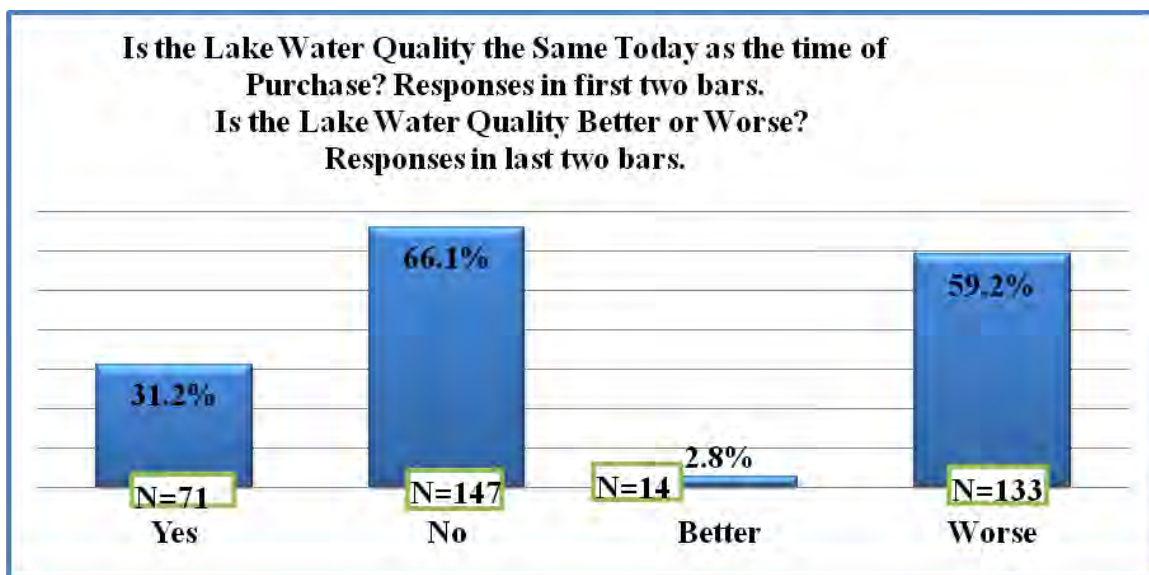
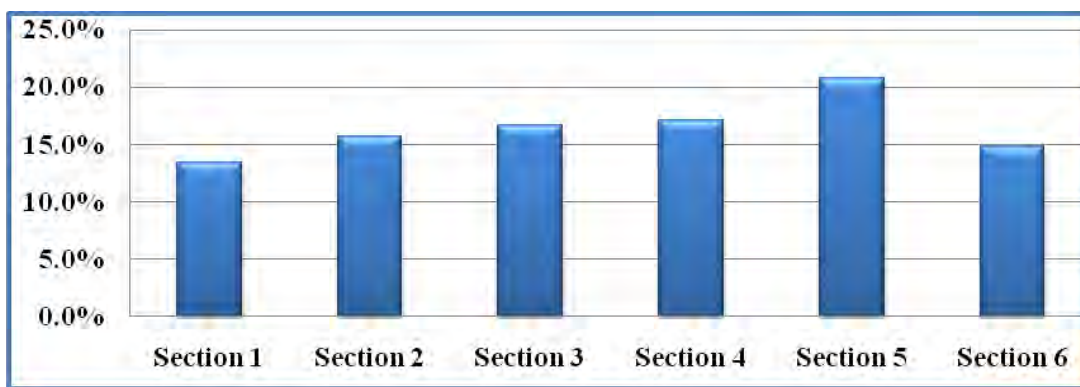


Figure 5 repeated. LCO Resident Location by Section

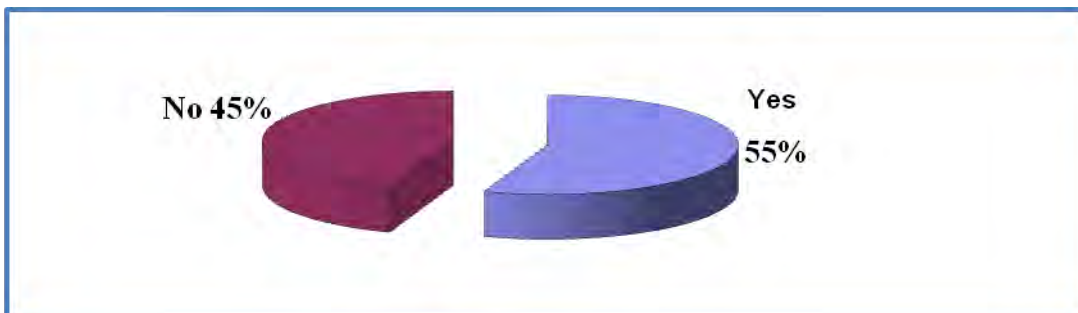


LCO Lake Areas (Sections), 1=N. Central Bay; 2=N. East Bay; 3=East Bay; 4=S East + Central Bays; 5= Lake around Victory Heights peninsula; 6= West Bay

(Q14) Perceived Property Value Impacts Survey respondents were asked if they believe their property value has been negatively affected by an increase of aquatic nuisance weeds or an increase of green cloudy water due to an increased abundance of algae up to the summer of 2010. Responses were fairly even split with about 55% of respondents believing their property values had declined because of water quality conditions in their LCO section (Figure 13). The median baseline

period for comparison of historical water quality conditions was approximately 24 years for this question. In total, 183 responses were received (or about 83% response rate).

Figure 13: LCO Resident Perception that Property Value Negatively Affected by Water Quality



(Q15) Potential Impact of Water Quality Conditions on Sawyer County Economy: Survey respondents were asked if they would continue to own/rent/recreate on LCO if the lake were to experience a decline in water clarity. Water quality degradation does appear to strongly influence intent to maintain property ownership with 20% saying “no” if average summer transparency declined 2 to 3 feet, 49% indicated “no” if average transparency declined 4-6 feet and 61% indicated they would not continue to own property on LCO if the loss of average summer clarity were to decline by 7-10 feet (Figure 14). Hence, lake water quality appears to be an important factor for maintaining property ownership. To put these ranges in perspective, average summer clarity measured in 2009 ranged from ~18 feet in the east and center bays to ~13 feet in the west bay and about 5.5 feet in Musky Bay.

Figure 14a: LCO Residents Future Decision “Not Staying” by Declines in Average Summer Clarity Loss.

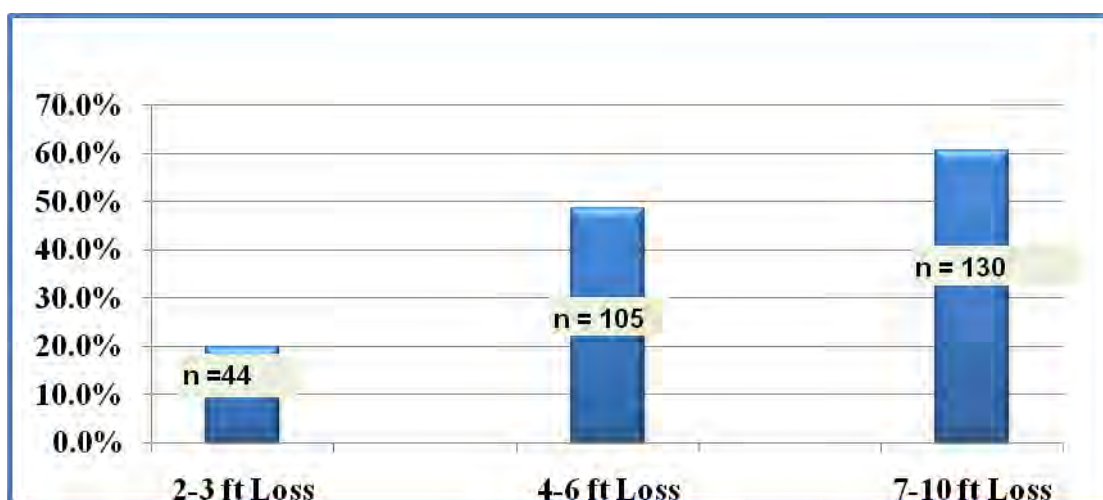
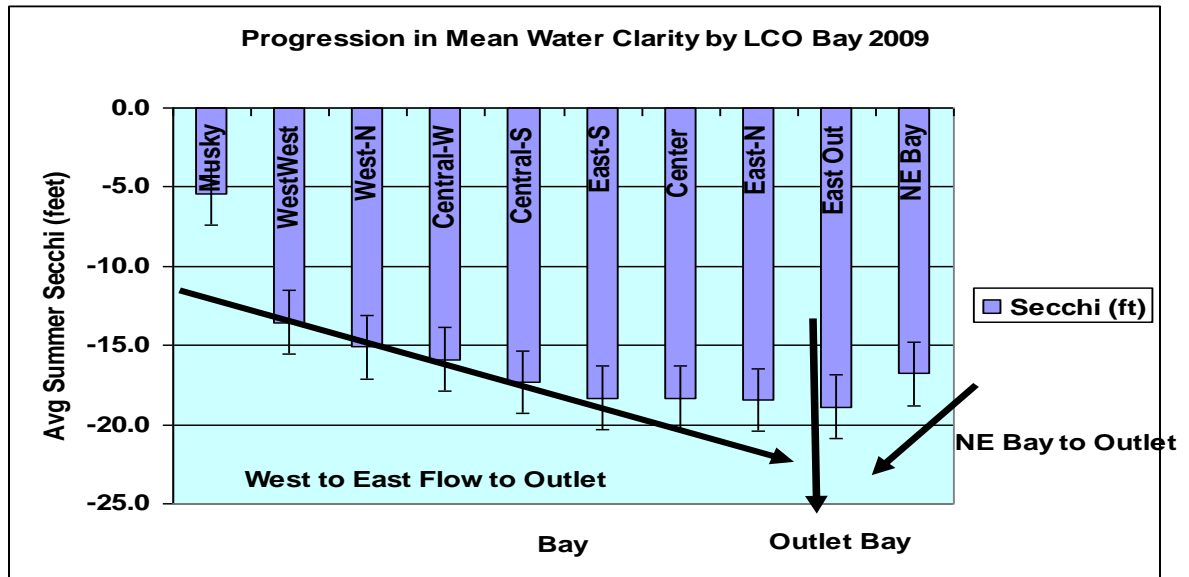


Figure 14b: Measured Average Summer Transparency



(Q16) Requested Goods & Services: Survey respondents were asked to suggest services or stores that they would like to see introduced or expanded in the area. Many suggestions included better road repair and maintenance, better road shoulders for bicycling, more bike trails, law enforcement relating jet skis, improved winter snow plowing, lake buoys for shoal areas, sporting equipment stores, Target, Sam's Club, wastewater treatment, cable TV, high-speed internet, marina/gas service on the lake and others. The most common requests focused on road maintenance, gas/marina on the lake and better cell phone reception, cable and internet services. It was also recommended that a Better Business Bureau would assist in minimizing unsatisfactory services.

Conclusions.

Major findings and conclusions from this survey and assessment include the following:

- The economic analyses included in this report were tabulated from mail-in survey responses and therefore the potential expenditures are likely under-reported by this method (respondents leaving blanks which were tabulated as "0"). The response rate was about 34% with 219 questionnaires returned for tabulation by late October, 2010, out of 650 distributed surveys.
- From survey respondent results extrapolated to 650 LCO residents, the annual lake use was estimated to be about 72,427 days from LCO related property owner (full-time and seasonal) with another 11,181 visitor days. Of these totals, the winter population was estimated to be about 7,706 days (about 9%).
- Many survey respondents travel significant distances from other homes in Iowa, Ohio, Florida, Kentucky, Arizona, Mexico, Kansas, Georgia, Texas and Hawaii. Survey respondents indicated that the majority of LCO seasonal (second home) residents are from Wisconsin (28%) and adjacent states Minnesota (49%), and Illinois (11%). Hence, dollars invested in Sawyer County businesses by LCO residents are largely being generated from out-of-region sources.

- The average survey respondent LCO household expenditure was \$15,939 with 98% indicating they shop in Hayward, 67% in Stone Lake, 36% at LCO Tribal Stores and 31% in Northwoods Beach.
- Most (85%) survey respondents were seasonal residents with an average of four persons per household.
- Survey responses were tabulated with non-real-estate expenditures totaling about \$3.3 million from 219 respondents. Extrapolating to the total LCO population (of 650 residences) is about \$9.8 million. Total impact to the regional economy was estimated to be on the order of \$10.8 million to \$14.8 million.
- Extrapolated LCO resident expenditures are approximately 5 times the estimated revenues generated from three LCO cranberry growing operations, based on standard industry yields and average revenue per barrel and 161 acres of operations.
- Sawyer County records for properties associated with LCO had an estimated fair market value totals for 2009 to be about \$ 331,115,485 with taxes totaling \$2,857,856
- Properties associated with two of three LCO cranberry growers had a total estimated fair market value of about \$1.8 million and contributed about \$15 thousand per year in taxes summarized by Sawyer County records. Hence, LCO 2009 resident total estimated fair market value was about 189 times those of properties associated with two LCO cranberry growers.
- Most survey respondents (52%) chose their property location because of the recreational opportunities with 57% desiring to maintain long-term family ownership of their property. Additionally, 11% of survey respondents indicated that they were planning on permanent LCO residency at some point in the future. These latter two findings have positive implications for providing long-term ownership stability to the region.
- Reinforcing these findings, survey respondents indicated long-term ownership with an average reported duration of about 32 years (Question 5) with many of these properties remaining in the same families for generations.
- Survey respondents overwhelmingly participate in water-related recreational activities (boating, swimming, fishing, canoeing/kayaking, and sailing).
- The majority of survey respondents (77%) indicated that lake water quality was excellent at the time of purchase (Question 5) but 59% indicated that water quality is worse today than at the time of purchase (Question 6). Survey respondent perceptions of degraded water quality were noted in all lake areas with perceived degradation particularly noted in LCO Sections 5 and 6 (lake areas surrounding Victory Heights and the West Bay, respectively). Various corroborating observations frequently cited in the survey included less clarity, more filamentous algae on rocks, loss of wildlife, loss of clams and more aquatic nuisance plants.
- Most survey respondents (55%) (Question 14) believe that their property values have been negatively impacted by present water quality.
- The degree of future water quality degradation appears to strongly influence future intent to maintain property ownership. Progressively larger losses in future summer water clarity resulted in greater percentages of survey respondents not desiring to continue ownership. Loss of 2 – 3 feet clarity resulted in 20% “not staying”, 4 – 6 feet loss resulted in 48% of responses “not staying” and loss of 7-10 feet clarity resulted in 59% “not staying”. These findings are noteworthy considering the widespread desire to maintain long-term family ownership of LCO properties.
- A significant majority of survey respondents contribute to local charities with typical donations varying from \$100 to \$540 per home. Tabulated contributions amounted to about \$64,000.

- Many suggestions for improving services were tabulated and included high speed internet, cable TV, improved road repair and maintenance, on-the-lake marina, sporting goods store, and discount stores.
- Preserving water quality conditions is essential to sustaining the quality of the Northwood „product“ and to continue to draw residents and visiting tourists from other states. Travel and tourism relies upon discretionary dollars that can be spent in other competing areas for better quality products and quality of experience. These survey results indicate that the majority of respondents perceive that the lake is degrading.
- LCO residents contribute to the Sawyer County economy by providing financial resources to support local employment with the purchase of goods and trades and, through property taxes, contribute to community infrastructure and public services.

References

- Anonymous, (2009). "Wisconsin's cranberry production hits new record". Site viewed by Bruce Wilson on October 30, 2010. <http://www.weau.com/home/headlines/38759847.html> Summary from Ocean Spray on Wisconsin Cranberry Production to WEAU.
- Boyle, K.J., S.R. Lawson, H.J. Michael, and R. Bouchard. 1998. "Lakefront Property Owners' Economic Demand for Water Clarity in Maine Lakes". Maine Agriculture and Forest Experiment Station Miscellaneous Report 410. University of Maine.
- City Data, 2010. Downloaded data from City Data.Com by Bruce Wilson on October 2, 2010. http://www.city-data.com/county/Sawyer_County-WI.html#ixzz13Eohz51X
- Davidson-Peterson Associates. 2010. The Economic Impact of Expenditures By Travelers On Wisconsin Tourism Federation of Wisconsin. Prepared for the Wisconsin Department of Tourism. Davidson-Peterson Associates, 201 Lafayette Center, Kennebunk, ME 04043.
- Eiswerth, Mark, R. Kashian, and M. Skidmore. 2005. "What is the Value of a Clean and Healthy Lake to a Local Community". Prepared for the Delevan Lake Improvement Association by the Fiscal and Economic Research Center at the University of Wisconsin--Whitewater
- Fitzpatrick, F.A, P.J. Garrison, S.A. Fitzgerald and J. F. Elder. 2003. Nutrient, Trace-Element, and Ecological History of Musky Bay, Lac Courte Oreilles, Wisconsin, as Inferred from Sediment Cores. United States Geological Survey. Middleton, WI.
- Heiskary, Steven and C. Bruce Wilson, 1995. Minnesota Lake Water Quality Assessment Report. Minnesota Pollution Control Agency, St. Paul, MN.
- Krysel, Charles, E.M.Boyer, C. Parson, and P. Welle, 2005. "Lakeshore Property Values and Water Quality: Evidence from Property Sales in the Mississippi Headwaters Region." Submitted to the Legislative Commission on Minnesota Resources.
- Larson, Sandra, 1980. Additions and Corrections to the Economic Portion of the Environmental Impact Statement, Bemidji Wastwater Treatment System, Beltrami County, MN. Minnesota Pollution Control Agency, St. Paul, MN.
- Michael, H.J., K.J. Boyle, and R. Bouchard. 1996. "Water Quality Affects Property Prices: A Case Study of Selected Maine Lakes". Maine Agriculture and Forest Experiment Station Miscellaneous Report 398. University of Maine.
- National Agricultural Statistics Service, US Department of Agriculture. 2010. Cranberry Forecast New England Agricultural Statistics, August 17, 2010. New England Agricultural Statistics.
- Northwest Regional Development Commission, 2010. Sawyer County Comprehensive Plan, Hayward, WI. Information from Table 1-12 on demographics and growth of the area communities.

Personal Communication (2009). Email with attached Excel spreadsheet from Mike Coleson to Bruce Wilson dated April 6, 2009 in response to request for information.

Spencer, Jim. 2006. Losing our lakes Part I: Rules Skirted and Lakes Under Attack. Minneapolis Star Tribune. July 6, 2010.

Wilson, C.B. 2010. Assessment of Lac Courte Oreilles for the Wisconsin Department of Natural Resources for Lake Planning Grant.

Wisconsin State Cranberry Growers Association (2010) "Wisconsin Cranberry Production". Site viewed by Bruce Wilson on October 1, 2010.

http://www.wiscran.org/special/libfile_files/media/103.pdf

U.S. Census Bureau, 2010. Downloaded data from US Census by Bruce Wilson on September 11, 2010. <http://www.census.gov/>

Appendix B



Blank page





Phosphorus Site-Specific Criteria Proposal for: Lac Courte Oreilles

AU ID: 15368

WBIC: 2390800

Sawyer County, Wisconsin



June 18, 2014

LimnoTech 

Water | Scientists
Environment | Engineers

Blank Page



Phosphorus Site-Specific Criteria Proposal for:

Lac Courte Oreilles

AU ID: 15368

WBIC: 2390800

Sawyer County, Wisconsin

Requestor:

The Courte Oreilles Lake Association (COLA)

612-839-8558

garylindapulford@charter.net

15790 West Victory Heights Circle

Stone Lake, WI 54876

In association with:

The Lac Courte Oreille Band of Lake Superior Chippewa Indians

715-634-0102

ddtyrold@cheqnet.net

LCO Conservation Department

13394W Trepania Rd. Bldg. 1

Hayward, WI 54843

June 18, 2014

Prepared by:

LimnoTech, Inc.

Blank page



TABLE OF CONTENTS

1 Site-Specific Criteria Proposal Overview	1
1.1 Potentially Interested Parties	1
1.2 Downstream Waterbodies	2
2 Description of Lac Courte Oreilles	3
3 Significance to Lac Courte Oreilles Band	5
4 Outstanding Resource Water Designation and Current Applicable Water Quality Criteria.....	7
4.1 Outstanding Resource Water (ORW) Classification	7
4.2 Total Phosphorus Criteria.....	7
4.3 Dissolved Oxygen Criteria	8
5 Fishery Impairment and Threats	9
5.1 Muskellunge	9
5.2 Cisco and Whitefish	10
6 Loss of Recreational Designated Use	11
7 Water Quality	13
7.1 Analysis of Total Phosphorus	13
7.1.1 Current Ambient Conditions.....	13
7.1.2 Historical Conditions	15
7.2 Verification of Biologic Condition	17
7.2.1 Chlorophyll <i>a</i>	17
7.2.2 Macrophytes	18
7.2.3 Dissolved Oxygen	19
7.3 Musky Bay Mixis Classification	22
8 Management for Climate Change.....	23
8.1 Climate Change Effects on Hypolimnetic Dissolved Oxygen.....	24
8.2 Predicted Effects on Cisco Populations	24
9 Proposed SSC	25
10 Modeling to Support Proposed SSC.....	27
10.1 Assessment of Improved Biologic Condition	27
10.2 Hydrodynamic Modeling	28
11 References	31



LIST OF FIGURES

Figure 1. Location of LCO within Wisconsin	4
Figure 2. LCO map showing tributaries, major basins and bays, sampling stations, and cranberry bog locations.	4
Figure 3. Algal mats in Musky Bay in September, 1999. (Source: USGS, 2003. Photo by Paul Garrison, WDNR.)	12
Figure 4. Annual mean and seasonal mean total phosphorus (June 1-Sept 15) in major bays and basins of LCO (2002-2013). Errors bars indicate ± 1 SD.	15
Figure 5. Total phosphorus concentrations in sediments of Musky Bay and Northeastern Bay, LCO with estimated date of deposition for the Musky Bay profile only. (Source: Figure 11; USGS, 2003).	16
Figure 6. Annual mean and seasonal mean chlorophyll a (July 15- Sept 15) in major basins and bays of LCO (2002-2013). Errors bars indicate ± 1 SD.	18
Figure 7. Seasonal mean hypolimnetic dissolved oxygen in major basins and bays of LCO (June - October 2013).....	20
Figure 8. Temperature and dissolved oxygen profiles in Musky Bay (station MB1), June through August 2013.....	21
Figure 9. Growing season length for Spooner, Wisconsin (USC00478027)	23
Figure 10. Predicted dye concentrations in LCO at two-week intervals following release of 100 mg/L in Musky Bay on June 1.....	29
Figure 11. Predicted daily average mass of dye slug in Musky Bay and West basin (percent). Dye was released in Musky Bay at 100 mg/L on June 1.....	30

LIST OF TABLES

Table 1. Distances of open water between each LCO bay and basin.	3
Table 2. Summary of WDNR 2012-2013 “two-story lake” surveys.	10
Table 3. Total phosphorus condition assessment for fish and aquatic life uses by LCO basin and bay.....	14
Table 4. Chlorophyll <i>a</i> condition assessment for fish and aquatic life uses by LCO basin and bay.....	17
Table 5. Summary of hypolimnetic dissolved oxygen in major basins and bays of LCO (June – October 2013).	19
Table 6. Present and future total phosphorus and hypolimnetic dissolved oxygen demand in LCO basins and bays.	28



1

Site-Specific Criteria Proposal Overview

This document defines phosphorus site-specific criteria (SSC) for Lac Courte Oreilles (LCO) located in Sawyer County, Wisconsin (WBIC 2390800). The SSC criteria are based on identified lost or threatened designated uses; water quality required for full attainment of these uses; and implementation of antidegradation policies for LCO.

The Lac Courte Oreille Band of Lake Superior Chippewa Indians, in association with the Courte Oreilles Lakes Association (COLA), is proposing SSC for LCO, based on consideration of these factors:

- Rare designation of LCO as an outstanding resource water (ORW);
- Existing impairments to warm-water fish populations (muskellunge) that have occurred since 1976;
- Increasing threats to most sensitive uses or cold-water fish species in the lake (cisco and whitefish);
- Loss of beneficial uses, including boating, fishing, and swimming in Musky Bay, the southwestern lobe of LCO;
- Water quality impairment for total phosphorus in Musky Bay and degradation of Stuckey Bay;
- Documented negative collective influence of Musky and Stuckey Bays on the water quality of LCO's West basin and subsequent downgradient basins and bays;
- Impacted biologic condition based on hypolimnetic dissolved oxygen (DO) levels below 6 µg/L in most of the major bays and basins of LCO;
- Expected impacts of climate change; and,
- The cumulative effects of the above considerations leading to continued degradation and further loss of beneficial uses of this rare designated outstanding resource water without additional protective standards.

The proposed total phosphorus SSC for LCO, to be applied to LCO in its entirety, is 10 µg/L. This is more protective than the current water quality criterion of 15 µg/L.

1.1 Potentially Interested Parties

Parties anticipated to be interested in this phosphorus SSC proposal for LCO include: the Lac Courte Oreilles Band of Lake Superior Chippewa Indians; COLA members; local cranberry bog owners; Great Lakes Indian Fish and Wildlife Commission (GLIFWC); lake and watershed residents; visitors to the lake for recreational activities; the Hayward Chamber of Commerce; local resorts; and the full spectrum of regional businesses and services (grocery stores, trades, home and recreation industry services, recreational fishing guides and outfitters). LCO is central to Tribal culture. It is also central to the region's economy with real estate valued at over \$332 million, annual property taxes of \$2.9 million,



supporting of local infrastructure, plus associated expenditures from residents and vacationers estimated to be about \$9.8 million to \$14.8 million per year (Wilson, 2008).

1.2 Downstream Waterbodies

Because the proposed SSC for LCO is more protective than the current applicable water quality criterion, a benefit to downstream waterbodies is expected. Waterbodies downstream of LCO include: Little Lac Courte Oreilles (WBIC 2390500), Billy Boy Flowage (WBIC 2389700), Couderay River (WBIC 2384700), and Grimh Flowage (WBIC 2385100). Downstream of the Grimh Flowage, the Couderay River flows into the Chippewa River (WBIC 2050000), which forms Lake Wissota near Chippewa Falls. A Total Maximum Daily Load (TMDL) for phosphorus exists for Little Lake Wissota, which is an embayment of Lake Wissota (WBIC 2152800). Further downstream the Chippewa River flows into Lake Pepin (WBIC 731800). Minnesota Pollution Control Agency is preparing a phosphorus TMDL for Lake Pepin but it has not been finalized. Improved water quality in LCO is not expected to significantly impact either TMDL.



2

Description of Lac Courte Oreilles

This section describes the location, drainage areas, and physical characteristics of LCO, which is located in Sawyer County, Wisconsin (Figure 1).

The lake has a total surface area of approximately 5,039 acres, with approximately 25 miles of shoreline. The maximum depth of LCO is 90 feet, its mean depth is 34 feet, and approximately 28% of the lake is less than 20 feet deep. Following commonly accepted limnological practice and terminology, the three bays (Musky, Stuckey, and Northeast) and three basins (West, Central, and East) comprise one lake referred to as Lac Courte Oreilles (Figure 2), which is identified by one lake identification number (Id# 2390800) and one common lake map <http://dnr.wi.gov/lakes/maps/DNR/2390800a.pdf>. All of the bays and basins are inter-connected and share one water level (relative to sea level except for short-term variations caused by wind, seiche, storm inflows, etc.). Musky, Stuckey and Northeast bays are not physically distinct upland lake basins connected to LCO by a predominant unidirectional streamflow or outlet structure. These bays share expanses of open water and hence, directly influence each other via advective and dispersive mixing. The distances of open water between each bay and basin are given in Table 1.

Table 1. Distances of open water between each LCO bay and basin.

Bay/Basin Interface	Length of Interface (ft)
Musky Bay/West Basin	1,980
Stuckey Bay/West Basin	770
Central Basin/West Basin	3,150
Central Basin/East Basin	2,565
East Basin/Northeast Bay	1,050

The total drainage area to LCO is 68,990 acres (99.5 square miles). Three tributaries drain 80% the watershed: Grindstone, Osprey, and Whitefish Creeks (Figure 2). Land cover/ use in the watershed is predominantly forested (53%) with the remainder being water (31%), grassland (8%), residential (4%), agriculture (4%), and commercial (0.1%) (Wilson, 2011). Five cranberry bogs are located within the drainage areas of Musky Bay, Stuckey Bay, West Basin, and East Basin (Figure 2).



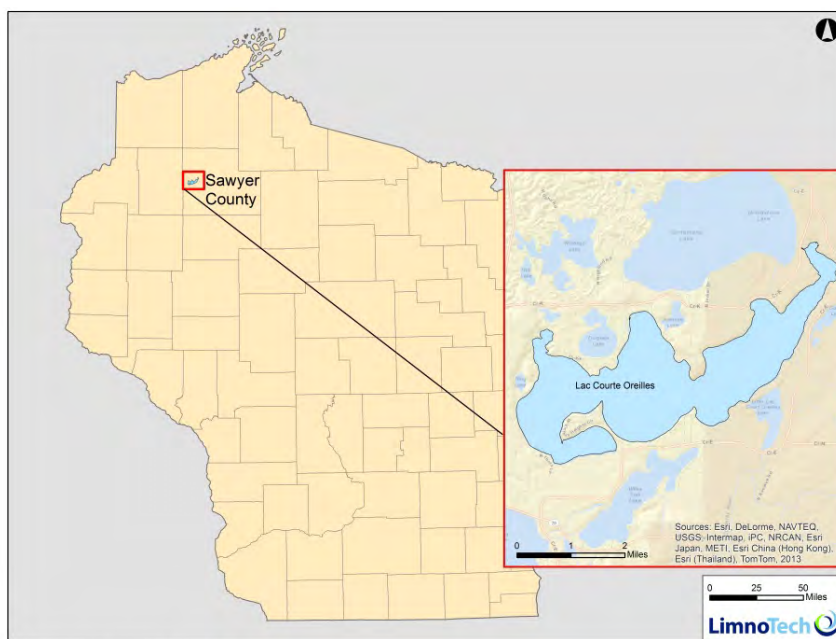


Figure 1. Location of LCO within Wisconsin.



Figure 2. LCO map showing tributaries, major basins and bays, sampling stations, and cranberry bog locations.

3

Significance to Lac Courte Oreilles Band

“Water, as it flows the rivers, lakes and streams, seeps underground passageways, or spurts out of the Earth’s surface as an artesian well – the Earth’s water system is compared to the human circulatory system in Ojibwe thought. So, the wellbeing of water, which affects every other living part of the Earth, is of vital importance to the Ojibwe people and to all people. Water, known as nibi in Ojibwemowin, is the source of life and, as such, becomes the responsibility of women. Nibi must be protected, kept pure, for all life now and to come.”¹

The 7,600 member Lac Courte Oreille Band of Lake Superior Chippewa Indians consists of a land base of 76,500 acres in northwest Wisconsin. The Lac Courte Oreilles Reservation, like much of northern Wisconsin, contains tremendous water resources. Numerous rivers, streams, lakes, ponds, and wetlands, as well as groundwater, make up the water resources landscape of the Reservation. In fact, nearly 20% of the total reservation area, or just over 15,000 acres of surface waters make the LCO reservation a “water rich” environment. All of these waters are located entirely within the Upper Chippewa River Basin. More than forty-three miles of rivers and streams, as well as all or portions of 26 named lakes can be found on the reservation. Additionally, over 7,500 acres of the reservation territory are classified as wetlands.

These water resources have provided subsistence, cultural, and spiritual benefits to many generations of Lac Courte Oreilles Ojibwe. The lakes of the reservation and the surrounding ceded territories, which includes Lac Courte Oreilles lake, contribute to Sawyer County’s status as one of the premier tourist areas in Wisconsin.

One-third of Lac Courte Oreilles lake is located within reservation boundaries, with the rest of the lake located within the ceded territory. Water quality degradation resulting from excessive levels of phosphorus in any portion of Lac Courte Oreilles Lake impacts the waters within the reservation boundaries due to mixing occurring between the various bays and basins.

The Lac Courte Oreilles Tribal Conservation Department (LCOCD) has been monitoring LCO since 1996 with routine monitoring beginning in 2002. The majority of the data presented in this document were collected by or in partnership with LCOCD.

¹ Integrated Resource Management Plan 2010 Lac Courte Oreilles Band of Lake Superior Ojibwe, pg. 25. Quoting: Seasons of the Ojibwe, 2002 Edition, Published by the Great Lakes Indian Fish and Wildlife Commission.



Blank Page



4

Outstanding Resource Water Designation and Current Applicable Water Quality Criteria

This section describes the current classifications of LCO and the water quality criteria currently applied to the lake.

4.1 Outstanding Resource Water (ORW) Classification

Lac Courte Oreilles is classified as an outstanding resource water (ORW) by Wisconsin Department of Natural Resources (WDNR). The lake was first listed as such in Wisconsin Administrative Code (WAC) NR 102.10 in 1993 (WAC, 1993).

Fewer than 1% of Wisconsin's lakes are designated as ORWs. Wisconsin's antidegradation rule (WAC NR 207) protects ORWs by only allowing new or expanded discharges if current water quality is maintained:

"If the department determines that a WPDES permit application proposes a new or increased discharge to outstanding resource waters, effluent limitations for substances in the new or increased portion of the discharge will be set equal to the background levels of these substances, upstream of, or adjacent to, the discharge site unless it is determined that for Great Lakes system waters, such limitations would result in significant lowering of water quality under s. NR 207.05 (4) (b). Effluent limitations for those substances shall be determined in accordance with s. NR 207.04."

4.2 Total Phosphorus Criteria

LCO has been designated as a deep (stratified) two-story cold-water fishery lake for purposes of applying water quality criteria for phosphorus. The WDNR's most protective total phosphorus criterion, 15 µg/L, has been applied to LCO (WAC NR 102.06).

WDNR has considered Musky Bay a separate, physically distinct, upland lake and characterized it as a shallow (non-stratified) drainage lake using the partial lakes assessment in the 2012 Wisconsin Consolidated Assessment and Listing Methodology (WisCALM; WDNR, 2012). The WDNR also determined that the applicable total phosphorus criterion for this class of lakes is 40 µg/L (WAC NR 102.06). Musky Bay was included on Wisconsin's 303(d) list in 2012 as impaired for total phosphorus.

Musky Bay, Stuckey Bay, and Northeast Bay are not physically separate upland lakes draining into LCO via streams or outlet structures. From a statewide policy consistency perspective, assigning separate upland lake standards to Musky Bay would suggest assignment of the same standards to Stuckey Bay and Northeast Bay, which would clearly violate antidegradation provisions of state and federal water rules. Musky Bay's water quality has been degraded and designated beneficial uses have been lost or threatened since passage of the federal Clean Water Act.



4.3 Dissolved Oxygen Criteria

For cold-waters in Wisconsin, dissolved oxygen may not be artificially lowered to less than 6.0 mg/L at any time or to less than 7.0 mg/L during spawning season (WAC NR102.04).



5

Fishery Impairment and Threats

LCO supports both warm-water and cold-water fish species. Of the warm-water species, muskellunge have been a highly sought after fish in LCO. Cold water species in LCO include cisco and whitefish. Populations of muskellunge are impaired in LCO, while whitefish and cisco populations are threatened.

Interaction occurs between the warm-water and cold-water fisheries; cold-water species are a key forage species for trophy gamefish. LCO produces world record muskellunge and large walleye, smallmouth, and northern, due to the presence of cisco and whitefish as food sources. Without the cold-water species, gamefish would be smaller, if not less abundant. The angling public would view this as a significant impairment (Pratt and Neuswanger, 2006).

5.1 Muskellunge

The report “Loss of Beneficial Uses, Musky Bay, Lac Courte Oreilles” (Pratt, 2013) presents data, analysis, and documentation of biological impacts in Musky Bay caused by elevated phosphorus discharges into the bay and internal phosphorus cycling in the bay. The documented impairments include: 1) depleted oxygen levels (discussed further in Section 7.2); 2) fish kills; 3) loss of muskellunge spawning habitat; 4) excessive macrophyte growth; and 5) loss of native macrophyte species as a result of curly leaf pondweed infestation (curly leaf pondweed impacts are discussed in Section 6).

Muskellunge, once present in large numbers predominantly in Musky Bay, are no longer reproducing in Musky Bay. No successful spawning has been documented in the bay since 1970 (Johnson, 1986). The cause of muskellunge decline was once thought to be competition with northern pike. However, removal of 60% of northern pike from Musky Bay in 2007 did not result in muskellunge reproduction (Pratt, 2007). Research on fish DNA in LCO showed a sustained genetic signature that would not exist if recruitment was entirely due to stocking; therefore natural reproduction of muskellunge must occur within LCO at locations other than Musky Bay (Sloss, 2006; Sloss et al. 2008; AFS 2003).

The evidence now points to oxygen depletion in Musky Bay, which occurs both during spawning season and during ice cover, as the cause of muskellunge decline. Dissolved oxygen depletion in Musky Bay is caused by two primary factors: 1) excessive inputs of phosphorus and 2) die-off of curly leaf pond weed (see Section 6).

The strain of muskellunge in LCO deposit their eggs at the bottom of the lake on the sediment surface (Pratt and Neuswanger, 2006). The eggs require 2 mg/L of dissolved oxygen to survive (Pratt, 2013). It is thought egg survival is hindered by the highly flocculent sediments present at the sediment surface in Musky Bay; the eggs sink into the flocculent layer, where very low or little oxygen exists, and die.

Other life stages of muskellunge are also impacted by low dissolved oxygen in the bay. Dissolved oxygen levels below 3 mg/L in lake bottom waters in the summer and in the water column in winter are known to cause stress and movement of muskellunge out of the low oxygen region (Pratt, 2013). With dissolved oxygen concentrations below 1 mg/L, all fish are severely stressed and some will die. At 0.5 mg/L dissolved oxygen, all fish will likely die. Dissolved oxygen conditions in Musky Bay are discussed in Section 7.2.



Winterkill data from WDNR's Hayward fisheries files indicates that Musky Bay accounts for two-thirds of the recorded fish kills in Sawyer County since 1996 (Pratt, 2013). Overall, there has been a decline in winterkills in Sawyer County from the 1960-1979 and 2000-2012 time periods from 35 to three. The trend in winterkills in Musky Bay is opposite of the countywide trend, with no winterkills between 1960-2002 and two winterkills in the 2003-2012 period.

5.2 Cisco and Whitefish

The most sensitive uses include cold-water fisheries, which are reliant on sufficient dissolved oxygen concentrations in the cooler bottom waters of a lake. Increased nutrient loading to a lake can result in a reduction of oxygen in the hypolimnion, as is seen in LCO (see Section 7.2). Die-offs of cold-water species may occur as these populations are driven into warmer surface waters.

LCO is considered to be among the three lakes with the best cold water fisheries that were surveyed for WDNR's 2012-13 two-story lake study (Kampa, personal communication, January 2014), which was focused on lakes in northwestern Wisconsin. The other top two lakes surveyed in this period are Grindstone and Whitefish Lakes, both of which drain into LCO. However, WDNR survey information indicates that both whitefish and cisco populations are threatened in LCO (Pratt, 2013). Only two whitefish were found in the survey (both in Whitefish lake).

Cisco populations are faring relatively well; however, there is evidence that cisco habitat is being compressed by lower dissolved oxygen levels and increased temperatures. In all three lakes, dissolved oxygen levels measured in the bottom waters are lower than the levels cisco are reported to prefer or able to withstand (Table 2).

Table 2. Summary of WDNR 2012-2013 “two-story lake” surveys.

Lake	Survey Date	Sets	No. Cisco (CPE)	No. Whitefish (CPE)	Water Depth (ft)	Temp. (°F)	DO (mg/L)
LCO	7-16-13	3	28 (9.3)	0	22-75	44-55	2.8-8.0
Whitefish	8/06-8/09-12	4	218 (5.5)	2 (0.5)	35-83	44-49	1.6-6.3
Grindstone	8-28-13	1	25 (25.0)	0	28-40	49-68	1.0-5.8

CPE= catch per effort

Summary of data from Jeff Kampa (Personal communication, January, 2014).

Whitefish, the presence of which is much rarer in general than cisco, are far more sensitive to dissolved oxygen levels than cisco. Whitefish prefer lower temperatures than cisco and therefore have an affinity to bottom waters. Their preferred summer habitat is approximately 10% or less by volume of cisco habitat (Pratt, personal communication, May 2014). LCO and Whitefish Lake are the only two known lakes in Wisconsin to date that don't contain lake trout but do contain both cisco and whitefish.



6

Loss of Recreational Designated Use

LCO draws thousands of visitors each year from Wisconsin, Minnesota, Illinois, and other states (Wilson, 2010). Approximately 20,000 fishing trips are conducted at LCO annually, with approximately 12% (2400 trips) conducted in Musky Bay. The total minimum value of these trips is estimated at \$700,000 per year, with \$75,000 per year in Musky Bay (Pratt and Neuswanger, 2006). However, recreational use of Musky Bay is impaired due to excessive aquatic plant growth and by the aquatic invasive species curly leaf pondweed, as well as by the presence of dense algal mats.

Curly leaf pondweed, first identified in the lake in 2005, is now established throughout Musky Bay. Its presence hinders or completely impairs recreational use of this portion of LCO for much of the year. Annual fish surveys have been conducted in the fall by WDNR and Great Lakes Indian Fish and Wildlife Commission (GLIFWC). Notes from the field surveys indicate whether navigation of Musky Bay was possible in the boom-shocker boat used in fisheries assessments, and therefore serve as a measure of fishing, boating, and swimming accessibility of Musky Bay.

The WDNR and GLIFWC survey notes document two levels of impairment to a successful fish survey: 1) survey made harder and less effective; and 2) survey cancelled or not completed. Since the surveys were conducted in the fall and not during the height of the growing season, they underestimate the level of impairment to navigation. Based on the fish survey field notes from 1992 to 2008, surveys at Musky Bay were completed with some difficulty in 1992, 1996, 1997. In 1998, 2003, and 2008, surveys were not able to be completed (field notes for these years were: “heavy weeds”, “not navigable”, and “motor fouling”). The Musky Bay station was permanently discontinued from the survey program in 2009 (Pratt, 2013).

While curly leaf pondweed has not been recognized as a biological impairment previously (e.g. 2012 WisCALM; WDNR, 2012), its presence contributes to impairment of LCO, including affecting native aquatic plant species and contributing to lowering of dissolved oxygen and increased nutrient levels during die off, which occurs in mid-summer (UW Extension, 2013).

COLA and WDNR have spent approximately \$40,000 per year on curly leaf pondweed control since 2010 in an effort to mitigate the phosphorus release/algal bloom and dissolved oxygen slump associated with curly leaf pondweed die off and to facilitate navigation in Musky Bay. Aquatic plant surveys were conducted in Musky Bay in 2007 and then in 2011 to assess the effectiveness of curly leaf pondweed control. Between 2007 and 2011, 48% of native species declined, 14% disappeared, and 65% remained stable in the bay (Stantec, 2012).

Algal mats, which are likely a manifestation of the excess phosphorus concentrations in Musky Bay, also periodically limit swimming, boating, and fishing in the bay (Figure 3).





Figure 3. Algal mats in Musky Bay in September, 1999. (Source: USGS, 2003. Photo by Paul Garrison, WDNR.)

7 Water Quality

In 2008 and 2010, COLA petitioned WDNR to list Musky Bay as an impaired water. Concern exists over water quality and biological conditions in Musky Bay as well as the influence of water quality in Musky Bay on conditions in LCO as a whole. The current 15 µg/L total phosphorus criterion that applies to LCO is not protective of LCO's designated beneficial uses, as evidenced by hypolimnetic dissolved oxygen conditions threatening cold water fish species as described in Section 5 and below in Section 7.2.

This section presents a summary of water quality conditions in LCO based on quality assured monitoring data collected by LCOCD. Data presented here span the 2002 to 2013 time period. Monitoring stations are indicated on Figure 2.

The focus of the presented data is on defining biological endpoints in LCO as defined for deep (stratified) lakes in WDNR's draft Site-Specific Criteria Framework for Wisconsin (2014a). The applicable thresholds are:

- Chlorophyll *a* does not exceed 20 µg/L for more than 5% of days during the summer (6 days), as calculated using 2012 WisCALM (WDNR, 2012) guidance².
- Macrophytes do not indicate an impairment. Note: specific metrics for assessment of this condition are under development.
- Dissolved oxygen in two-story fishery lakes, such as LCO, must meet the above thresholds for chlorophyll *a* and macrophytes, and must also have dissolved oxygen >6 mg/L in the hypolimnion.

Total phosphorus, chlorophyll *a*, macrophyte, and dissolved oxygen conditions in LCO are presented below. In addition, temperature conditions in Musky Bay are presented that demonstrate the bay's intermittently stratified nature.

7.1 Analysis of Total Phosphorus

This section presents an analysis of current ambient total phosphorus conditions in LCO and historical total phosphorus conditions based on sediment cores.

7.1.1 Current Ambient Conditions

Epilimnetic total phosphorus data for seven LCO sampling stations (LCO 1 thru 6 and MB1; Figure 2) were analyzed according to the assessment protocols for fish and aquatic life uses described in 2014 WisCALM (WDNR, 2013) for the June 1 to September 15 season. While data are available dating back to 2002, the most recent five-year period for each station was chosen, except where additional qualifying years were necessary to total five years. Therefore, data used in the analysis span the time period of 2007 to 2013. The impairment analysis was conducted for each major basin and bay in LCO. The results of the

² Note: Data presented in this proposal were assessed using protocols established in 2014 WisCALM (WDNR, 2013).



assessment, including the “grand mean” for each basin and bay, the associated confidence interval, and the resulting assessment category are given in Table 3, along with the criteria thresholds and appropriate impairment “decision”. The number of monthly means used for each basin and bay and the associated monitoring time periods are also given in the table.

Table 3. Total phosphorus condition assessment for fish and aquatic life uses by LCO basin and bay.

Bay/Basin	Musky Bay	Stuckey Bay	West Basin	Central Basin	East Basin	Northeast Bay
Total no. daily averages	81	46	38	38	92	38
No. months in grand mean	28	19	17	16	24	17
Period of record	2007-2013	2007-2013	2007-2013	2007-2013	2007-2013	2007-2013
No. years used	7	6	6	6	7	6
Grand Mean	35.4	18.1	14.7	11.0	11.6	11.8
Lower 90% Confidence Interval	33.3	11.8	10.1	8.6	10.5	10.1
Upper 90% Confidence Interval	37.6	24.3	19.2	13.4	12.7	13.5
Recreational Use (REC) Threshold	15	15	15	15	15	15
Fish and Aquatic Life Use (FAL) Threshold	15	15	15	15	15	15
REC Assessment	Clearly exceeds	May exceed	May meet	Clearly meets	Clearly meets	Clearly meets
FAL Assessment	Clearly exceeds	May exceed	May meet	Clearly meets	Clearly meets	Clearly meets

Based on the assessment, total phosphorus concentrations are highest in Musky Bay, indicating both recreational and fish and aquatic life use impairments when compared to the 15 µg/L threshold for two-story fishery, deep drainage lakes. In Stuckey Bay and West Basin (Figure 2), total phosphorus concentrations are of potential concern for both fish and aquatic life uses and recreational use. Central Basin, East Basin, and Northeast Bay are meeting total phosphorus mean concentration criteria.

Despite the majority of LCO meeting current total phosphorus criteria, LCO has an impaired biologic condition evidenced by low dissolved oxygen (<6 mg/L) in the hypolimnion as discussed in Section 7.2. This indicates that LCO is more sensitive to total phosphorus inputs than average lakes of its kind. This possibility is recognized by WDNR in their 2014 draft Site-Specific Criteria Framework for Wisconsin, which states “...waterbodies may be more sensitive to phosphorus and experience biological responses and use impairments at lower levels than usually expected.”

Mean annual and seasonal total phosphorus concentrations for the 2002 to 2013 period are provided for the major LCO basins and bays in Figure 4.



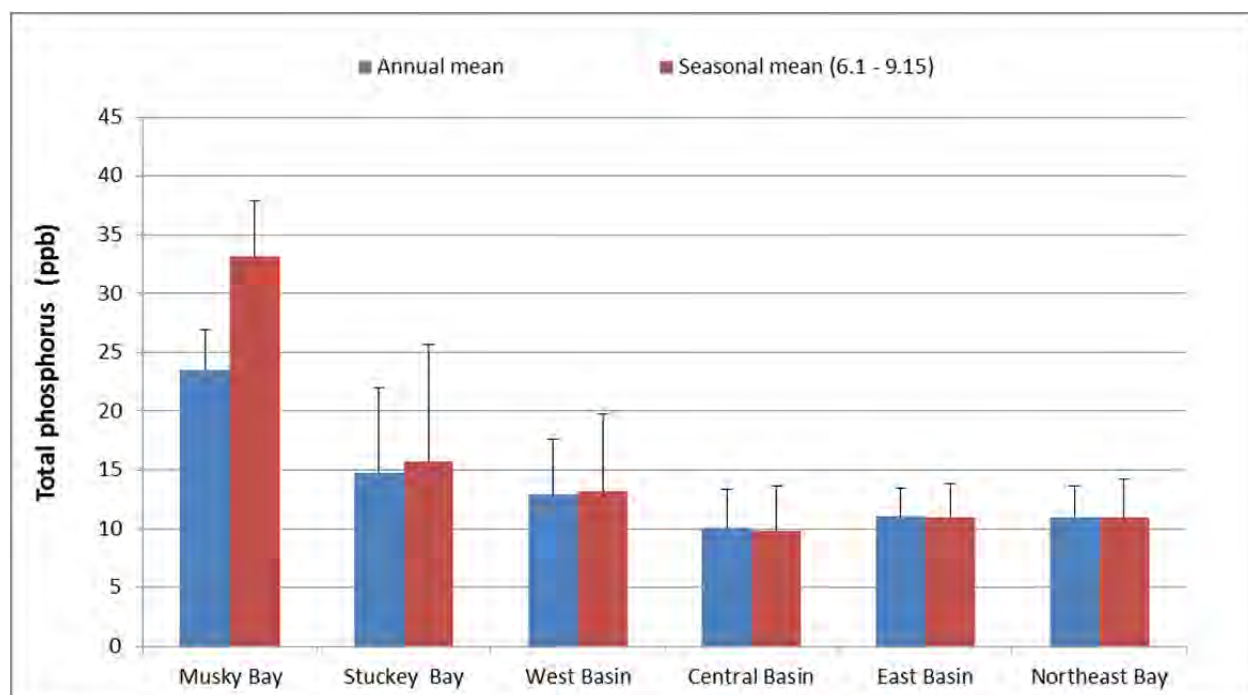


Figure 4. Annual mean and seasonal mean total phosphorus (June 1-Sept 15) in major bays and basins of LCO (2002-2013). Errors bars indicate ± 1 SD.

7.1.2 Historical Conditions

Historical water quality patterns in LCO were examined by USGS based on analyses of sediment cores collected in 1999 and 2001 (Fitzgerald et al, 2003). Cores were collected in Musky Bay (five locations), Northeastern Bay (two locations), Stuckey Bay, and the center of the lake (deep hole). Samples from the cores were analyzed for minor and trace elements, nutrients, biogenic silica, diatoms, pollen, and radioisotopes.

The cores from one of the Musky Bay sites in the study (MB-1) indicated that since the 1980's, phosphorus levels increased dramatically in the bay while iron levels decreased almost as dramatically (from approximately 7:1 to approximately 1:1). The lower phosphorus to iron ratios indicate a likelihood of internal phosphorus release (USGS, 2003). Study results indicated that the histories of several elements in Musky Bay, including phosphorus, were confounded by organic-matter decomposition and chemical redistribution (possibly by macrophytes) after deposition, thus limiting their use for reconstructing historic nutrient inputs. Dating of the cores from Northeastern Bay was not possible due to disturbances that happened after deposition as indicated in the radioisotope profiles. Total phosphorus core profiles for Musky Bay and Northeastern Bay from the USGS (2003) study are shown in Figure 5.

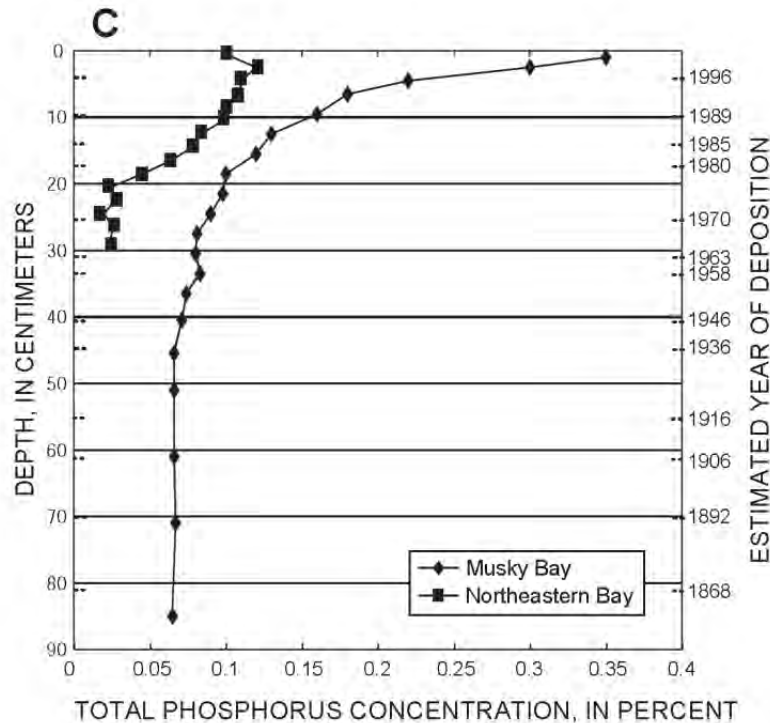


Figure 5. Total phosphorus concentrations in sediments of Musky Bay and Northeastern Bay, LCO with estimated date of deposition for the Musky Bay profile only. (Source: Figure 11; USGS, 2003).

Evaluation of the silica, diatom, and pollen data from the Musky Bay sediment cores indicated an increased growth of aquatic plants during the 25 years preceding the study and establishment of floating algal mats in the preceding decade. Increased nutrient inputs to Musky Bay were indicated after approximately 1940 and also in the 1990s by several lines of evidence (USGS, 2003).

WDNR's draft guidance for site-specific criteria (WDNR, 2014) requires the use of a sediment core to establish historical water column total phosphorus concentrations in cases where total phosphorus concentrations are not exceeding statewide criteria but the biology is impaired and a more stringent SSC is sought. The guidance specifies that the core is to be collected from the deepest part of the lake.

Paul Garrison at WDNR was contacted regarding the possibility of discerning a pre-development total phosphorus concentration for LCO based on the deep hole sediment core collected for the USGS study. Based on this request, diatoms in both the top and bottom sample from the top/bottom core collected at the deep hole location were re-counted and the results run through a weighted average model for deep lakes (Birks, et al., 1990). A concentration of 10 µg/L was predicted in the top sample. The model was not able to accurately predict total phosphorus concentrations in the deep hole bottom sample due to limitations in the model (Garrison, 2014). Collection of new samples would not improve the ability to predict pre-development total phosphorus concentrations (Garrison, personal communication, May 2014).

7.2 Verification of Biologic Condition

LCO's biologic condition was assessed based on its classification as a deep lake and a two-story fishery. Chlorophyll *a*, macrophytes, and dissolved oxygen conditions in the lake are described below.

7.2.1 Chlorophyll *a*

As with the total phosphorus analysis described in Section 7.1, epilimnetic chlorophyll *a* data for seven LCO sampling stations (LCO 1 thru 6 and MB1; Figure 2) was analyzed according to the assessment protocols for fish and aquatic life uses described in 2014 WisCALM (WDNR, 2013) for the July 15 to September 15 season. Data were not analyzed for recreational use impairments since chlorophyll *a* concentrations in LCO are generally below impairment levels; only five out of 201 total chlorophyll *a* samples had concentrations greater than 20 µg/L, all of which were located in Musky Bay.

While data are available dating back to 2002, the most recent five-year period for each station was chosen, except where additional qualifying years were necessary to total five years. Therefore, data used in the analysis span the time period of 2007 to 2013. The impairment analysis was conducted for each major basin and bay in LCO. The results of the assessment, including the “grand mean” for each basin and bay, the associated confidence interval, and the resulting assessment category are given in Table 4, along with the criteria thresholds and appropriate impairment “decision”. The number of monthly means used for each basin and bay and the associated monitoring time periods are also given in the table. Based on the assessment, all bays and basins except Musky Bay meet fish and aquatic life uses based on chlorophyll *a*.

Table 4. Chlorophyll *a* condition assessment for fish and aquatic life uses by LCO basin and bay.

Bay/Basin	Musky Bay	Stuckey Bay	West Basin	Central Basin	East Basin	Northeast Bay
Total no. daily averages	46	28	22	22	61	22
No. months in grand mean	20	14	12	11	19	11
Period of record	2007-2013	2007-2013	2007-2013	2007-2013	2007-2013	2007-2013
No. years used	7	6	6	6	7	6
Grand Mean	9.8	2.4	2.0	1.7	2.0	2.0
Lower 90% Confidence Interval	7.9	2.0	1.6	1.5	1.8	1.7
Upper 90% Confidence Interval	11.8	2.7	2.3	1.8	2.2	2.3
Fish and Aquatic Life Use (FAL) Threshold	10	10	10	10	10	10
FAL Assessment	May meet	Clearly meets	Clearly meets	Clearly meets	Clearly meets	Clearly meets

Mean annual and seasonal chlorophyll *a* concentrations for the 2002 to 2013 period are provided for the major LCO basins and bays in Figure 6.



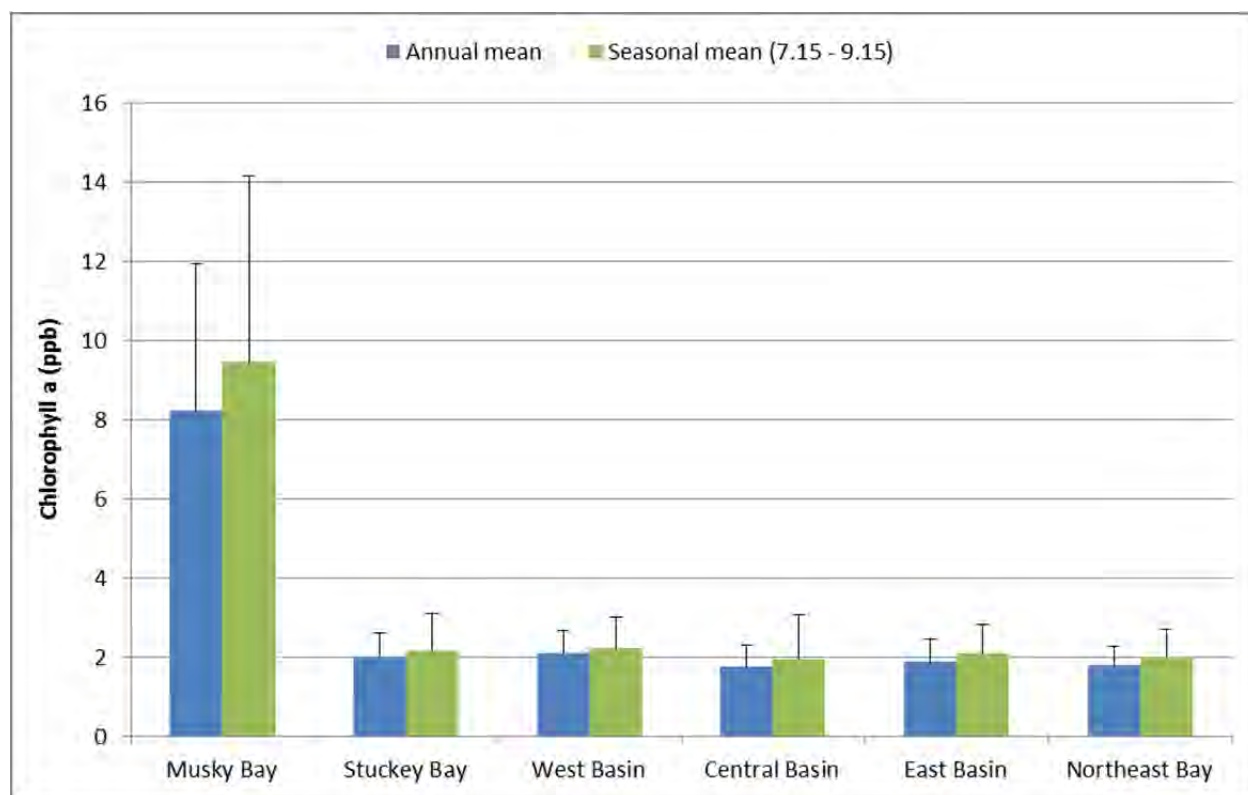


Figure 6. Annual mean and seasonal mean chlorophyll a (July 15- Sept 15) in major basins and bays of LCO (2002-2013). Errors bars indicate ± 1 SD.

7.2.2 Macrophytes

Point intercept surveys were conducted in LCO in 2007 (Musky Bay) and 2010 (lakewide) following WDNR protocols. In addition, a visual shoreline survey was completed in June 2010 to look for the presence of invasive species. The results of these surveys are documented in Macrophyte Survey Musky Bay-Lac Courte Oreilles (Harmony, 2007) and Appendix B of the Lac Courte Oreilles Aquatic Plant Management Plan (Tyrolt, 2011).

The 2010 point-intercept survey was conducted in August using a 2,254 point grid generated by WDNR. Based on this survey, LCO has a very diverse plant community with a total of 36 species (35 native and one exotic). Species abundance is balanced between the different types of plants. The Simpson's diversity index of 0.94 calculated based on 2010 study results indicates a healthy ecosystem and a high degree of diversity (Tyrolt, 2011).

The floristic quality index (FQI) calculated for LCO was 36.0 with 33 species used. The mean conservatism value was 6.27. The number of species and FQI are greater than the median values for lakes in the same eco-region (Northern Lakes and Forests), while the mean conservatism value is slightly lower. The high FQI is indicative of a plant community that is healthy, intolerant to development and other human disturbances in the watershed, and has changed little in response to human impact on water quality and habitat changes. This value also indicates a high degree of water quality (Tyrolt, 2011).

Musky Bay has a robust and diverse plant community (Tyrolt, 2011); however, the community structure is being negatively influenced by curly leaf pondweed infestation as described in Section 6. Several other areas of LCO are impacted by curly lead pondweed, including Northeast Bay (Barbertown Bay) and

Stuckey Bay. Grindstone Bay is being watched due to the presence of curly lead pondweed in Little Grindstone Lake, which flows into the bay (Tyrolt, 2011).

7.2.3 Dissolved Oxygen

Dissolved oxygen is a biologic impairment indicator for two-story fishery lakes (WDNR, 2014). A concentration of 6 mg/L must be maintained in the hypolimnion in these lakes to support the cold water fishery.

To assess hypolimnetic dissolved oxygen conditions in LCO, profiles of temperature and dissolved oxygen collected at seven LCO stations (LCO 1 thru 6 and MB1; Figure 2) in 2013 were evaluated. Monitoring was conducted on a total of 19 dates between May 28 and October 17; Not all stations were monitored on each date. Each depth profile was visually inspected to evaluate whether the lake was stratified at the time of monitoring. The lake stratified at all stations, including MB1 in Musky Bay, during the monitoring period. For dates where stratified conditions existed, professional judgment was used to select depths at which measurements were located within the hypolimnion. Hypolimnetic dissolved oxygen measurements were then averaged for each date by station. Stratification conditions in Musky Bay are discussed further in Section 7.3.

Table 5 presents a summary of dissolved oxygen concentrations by major bay and basin, as well as the percent exceedance of the 6 mg/L impairment threshold. Where more than one station was sampled in a basin or bay, daily values were averaged by basin or bay. Mean hypolimnetic dissolved oxygen for the 2013 monitoring period is shown in Figure 7.

Table 5. Summary of hypolimnetic dissolved oxygen in major basins and bays of LCO (June – October 2013).

Bay/Basin	Mean DO (mg/L)	Min DO (mg/L)	Max DO (mg/L)	Count of Daily Means	% Less than 6 mg/L
Musky Bay	3.24	0.85	9.87	11	82%
Stuckey Bay	8.44	6.11	11.24	9	0%
West Basin	2.23	0.04	8.43	19	84%
Central Basin	3.50	0.13	9.78	19	68%
East Basin	5.47	0.04	11.20	32 (two stations)	44%
Northeast Bay	7.99	5.95	11.22	14	7%



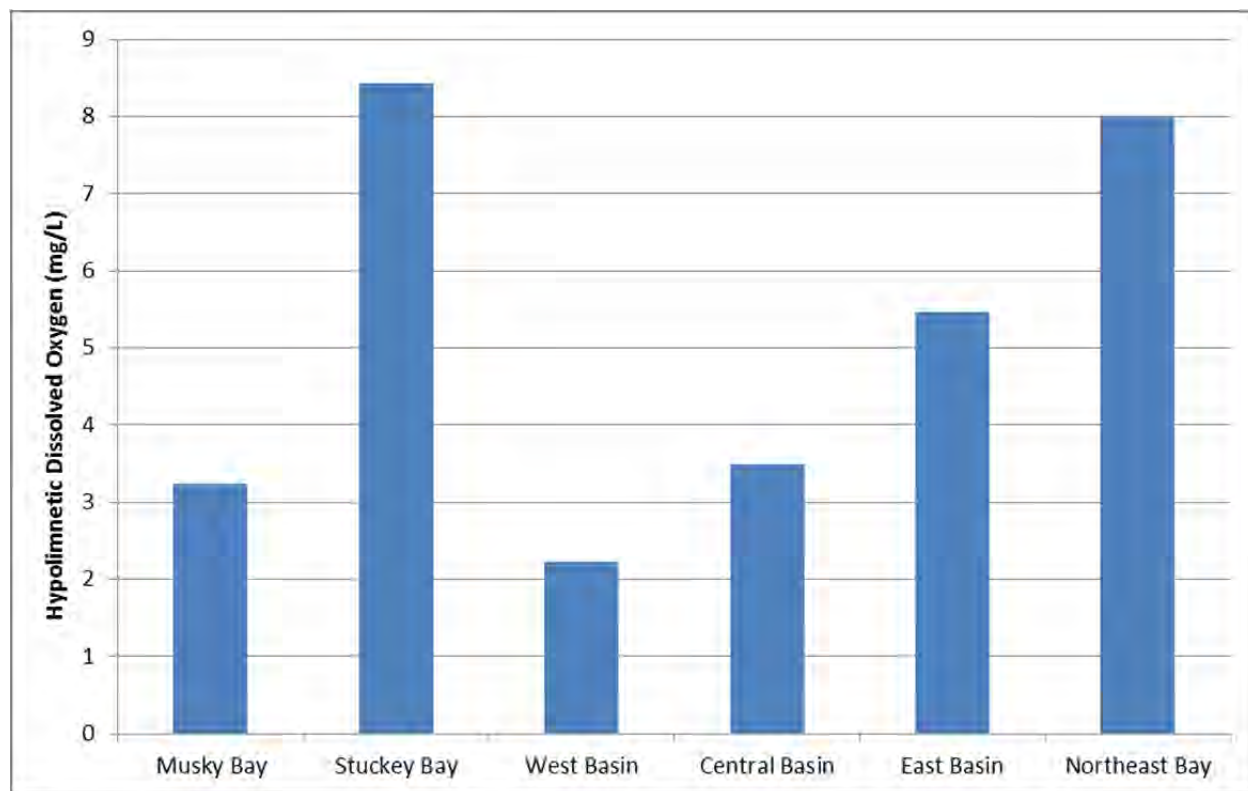


Figure 7. Seasonal mean hypolimnetic dissolved oxygen in major basins and bays of LCO (June - October 2013).

All basins and bays but Stuckey Bay had at least one daily average hypolimnetic dissolved oxygen concentration below 6 mg/L (Table 5). Means for 2013 were below 6 mg/L in Musky Bay, West Basin, Central Basin, and East Basin. Data was available for more than 10 dates in 2013 for all basins and bays except Stuckey Bay. The percent of monitoring days where average hypolimnetic dissolved oxygen was below 6 mg/L was greater than 10% in all locations except Stuckey Bay and Northeast Bay, with the rest of the percent noncompliance exceedances ranging from 44% to 84%. These results indicate an impairment of the biologic condition of LCO based on its designation as a two-story fishery lake.

Low hypolimnetic dissolved oxygen conditions in Musky Bay are also of a concern for muskellunge reproduction as discussed in Section 5.1. Temperature and dissolved oxygen profiles for 2013 Musky Bay data are presented in Figure 8.

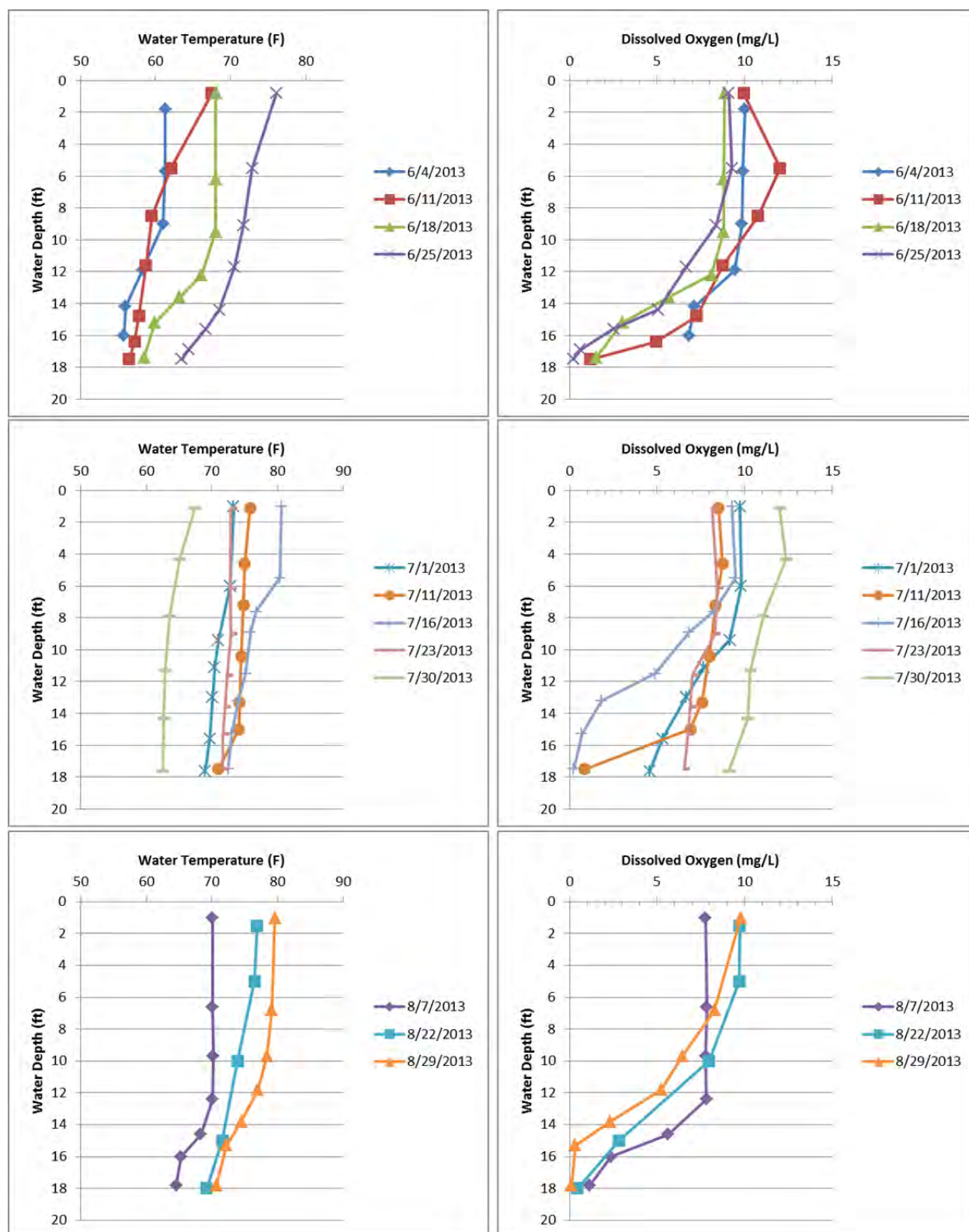


Figure 8. Temperature and dissolved oxygen profiles in Musky Bay (station MB1), June through August 2013.

Muskellunge spawn in the spring when water temperatures reach 48 to 59 degrees and may sometimes spawn again approximately two weeks later (Pratt, personal communication, 2014). As previously mentioned, a dissolved oxygen concentration of 2 mg/L at the sediment surface is required for egg survival (Pratt, 2013). Based on the 2013 monitoring data, dissolved oxygen conditions in the bottom waters of Musky Bay were already below 2 mg/L on June 11 while water temperatures were still within the muskellunge spawning temperature range.

7.3 Musky Bay Mixis Classification

Temperature and dissolved oxygen profiles were collected in Musky Bay by the LCOCD on nine dates in 2013, as shown in Figure 8 by month. As indicated in Figure 8, Musky Bay stratifies and then mixes (between 6/25 & 7/1 and between 7/16 & 7/23) at least twice during the monitoring period. During stratification, hypolimnetic dissolved oxygen levels are consistently below 5 mg/L and frequently between 0 and 3 mg/L.

For its most recent assessment, WDNR classified Musky Bay as a shallow lake. This is presumably due to the automatically generated lake classification determined using the Lathrop/Lillie equation. Given a surface area of 301.8 acres and a maximum depth of 18 feet for Musky Bay, a ratio of 2.6 results. Since this value is less than 3.8, the bay would be classified as shallow (2014 WisCALM; WDNR, 2013). However, 2014 WisCALM (WDNR, 2013) states that “use of field data on depth, area, residence time, and temperature profiles to refine the model-based lake classifications is encouraged.” The evidence of stratification in Musky Bay based on 2013 monitoring data supports its classification with the rest of LCO as a deep drainage lake according to 2014 WisCALM (WDNR, 2013), which also states “stratified lakes exhibit thermal layering throughout the summer or they undergo intermittent stratification”. Regardless of the mixis classification, Musky Bay is prone to thermal and oxygen stratification periods that strongly and negatively influence habitat and biological integrity of Musky Bay and LCO in its entirety. These periods of anoxia are influenced by the degree of nutrient loading (stressor).



8

Management for Climate Change

Climate change poses very real present and future threats to LCO's cold-water fishery. According to the Wisconsin Initiative for Climate Change Impacts (WICCI, 2011), northwest Wisconsin has seen the largest gains in growing season length of approximately two to three weeks since 1950 (see Figure 9); the largest increases in winter temperatures (up to 4.5 degrees F); and the largest increases in springtime temperatures of about 3.5 degrees F. In northern Wisconsin, mean annual air temperature is predicted to increase by 2.7 to 12.6 degrees F by 2100 (IPCC 2013; Palmer et al. 2014).

The WICCI report also concluded that since 1950 to 2006, northwest Wisconsin had increasing dry periods along with an increase in the number of intense precipitation events. The new National Oceanic and Atmospheric Administration (NOAA) Atlas 14 for Wisconsin (NOAA, 2013) estimated that the 24-hour storm with annual to 100 year recurrences ranged from 2.12 inches to 6.74 inches. The magnitude of back-to-back storms occurring over two to ten day periods ranged from 2.8 to 4.5 inches (annually) to 4.56 to 6.73 inches (every 10 years). Hence, the wet periods can be expected to produce substantial runoff to LCO.

Recent research on predicted impacts to cold-water lakes in Wisconsin and Minnesota is described below.

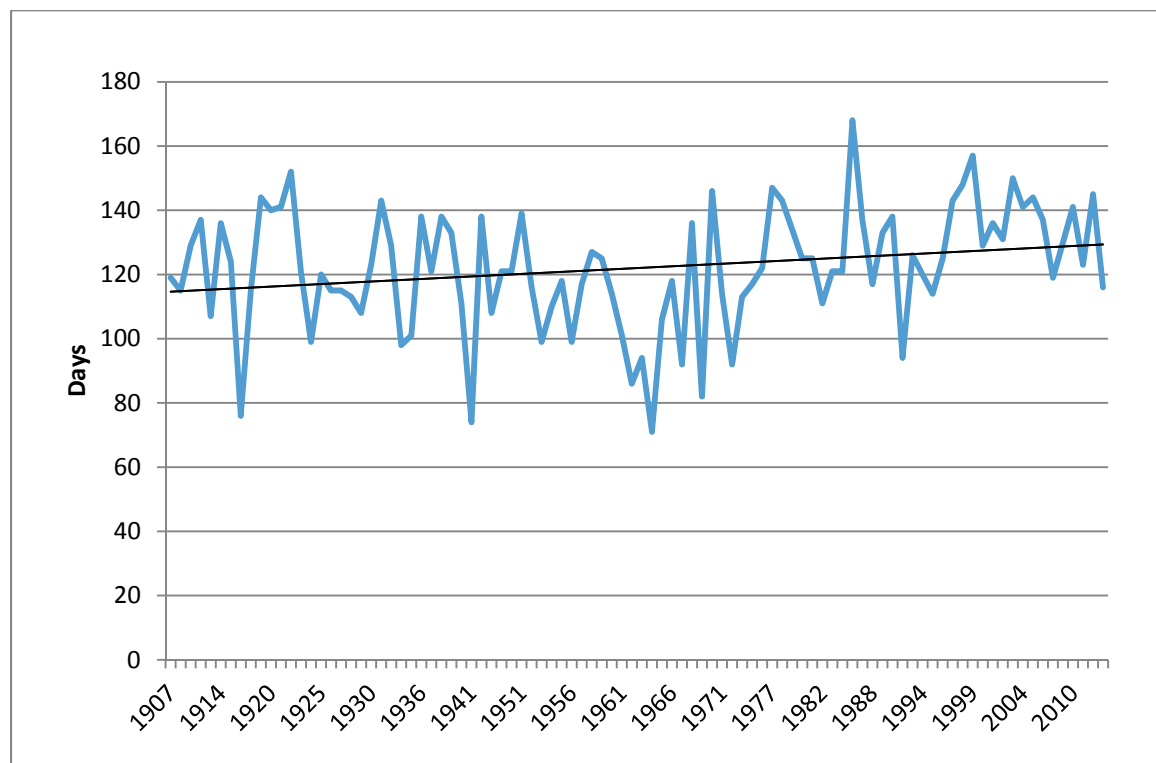


Figure 9. Growing season length for Spooner, Wisconsin (USC00478027)



8.1 Climate Change Effects on Hypolimnetic Dissolved Oxygen

Increased air and surface water temperature can lead to an earlier onset of stratification, which lengthens the summer stratification period (Sharma et al., 2011; Palmer et al., 2014). Additionally, increased average fall air temperature can delay turnover events. In Lake Mendota (Madison, Wisconsin), one study predicted that a 3-6°C increase in average fall air temperature would likely delay fall turnover by 5-10 days (Robertson and Ragotzke, 1990; Palmer et al., 2014). Under these conditions, a more stable thermocline and shallower mixed layer develops, resulting in prolonged periods of hypoxic or anoxia conditions in the hypolimnion (Palmer et al., 2014).

In LCO, low hypolimnetic dissolved oxygen (≤ 6 mg/L) has been measured on multiple occasions in Musky Bay, Stuckey Bay, West Basin, Central Basin, East Basin and the Northeast Basin (2002-2013). Elevated total phosphorus in Musky Bay has contributed to nuisance algal growth leading to loss of beneficial use and listing on the 2012 303 (d) impaired waters list. Progression to eutrophication through elevated total phosphorus inputs can be expected in this mesotrophic system, which would exacerbate current hypolimnetic dissolved oxygen conditions and likely amplify the complex effects of climate change in LCO.

8.2 Predicted Effects on Cisco Populations

Late summer conditions can be particularly critical for cold-water fisheries. As surface waters warm and hypolimnetic dissolved oxygen decreases, suitable habitat for cold-water fishes like cisco become limiting (Fang et al., 2010). These conditions can lead to summertime fish kills and decreased growth rates for cisco (Sharma et al. 2011). Cisco has been studied as a sentinel of climate change and is a species of concern in Wisconsin (Sharma et al., 2011). A 5°C increase in mean annual air temperature in Wisconsin is projected to reduce cisco populations by as much as 50%. Loss of habitat through warmer waters and lower dissolved oxygen has resulted in declining cisco populations in several northern Wisconsin lakes (Sharma et al., 2011). Furthermore, increased rates of organic matter deposition driven by eutrophication can be devastating to cold-water fisheries that depend on cold, well-oxygenated hypolimnetic waters for refugia during summer stratification (Jacobson et al. 2010).

If cold-water fisheries are managed without consideration of these issues, many cisco populations in this region may face extirpation by 2100 as a result of ongoing climate change (Sharma et al., 2011). As discussed in Section 5.2, whitefish are even more sensitive to changes temperature and dissolved oxygen conditions than cisco, as they prefer the bottommost waters. Climate change impacts to whitefish would therefore be greater than those predicted for cisco. As lake productivity is influenced by nutrient inputs from the surrounding landscape, management actions to reduce excessive nutrient inputs to cold-water fisheries may limit degradation of suitable habitat for sensitive species.



9

Proposed SSC

A value of **10 µg/L** is being proposed as the site-specific total phosphorus criterion for LCO in order to restore and protect designated uses and as to guide antidegradation policies. This value must be applied to LCO in its entirety, including all of its natural basins and bays, which are one integrated aquatic system

This SSC for LCO in its entirety is proposed based on the following:

1. Following commonly accepted limnological practice and terminology, the three bays (Musky, Stuckey, and Northeast) and three basins (West, Central, and East) comprise one lake referred to as Lac Courte Oreilles and are identified by one lake identification number (ID # 2390800);
2. All of the bays and basins are inter-connected and share one water level (relative to sea level except for short-term variations caused by wind, seiche, storm inflows etc.);
3. Documented impairments in Musky Bay even while the bay was meeting its WDNR-applied 40 µg/L total phosphorus criterion;
4. The direct connection of Musky Bay to LCO and, therefore, its influence on water quality in the rest of LCO;
5. Stratification status of Musky Bay as “deep” based on temperature profiles collected in the bay;
6. Evidence of significant increases in phosphorus loading to LCO since pre-settlement conditions based on the sediment diatom record;
7. Despite attainment of current total phosphorus criteria (15 µg/L) in LCO, a biologic impairment exists in the lake due to dissolved oxygen concentrations below 6 mg/L in the hypolimnion, indicating negative impacts to the cold water fishery in LCO;
8. Dissolved oxygen levels in the flocculent sediment at the bottom of Musky Bay are below concentrations necessary for muskellunge egg survival during spawning season; and,
9. The need to proactively protect against future degradation of fish populations due to climate change through watershed management practices.

Based on a review of available scientific literature, 10 µg/L was selected for LCO as appropriate for protection of water quality and the cold water fishery. A thorough review of phosphorus, dissolved oxygen, secchi depth, and chlorophyll *a* levels and health of various cold and warm-water fish species in Minnesota lakes can be found in Heiskary and Wilson (2005) and Heiskary and Wilson (2008). The important findings from these studies that support the proposed 10 µg/L total phosphorus criterion for LCO are:

- Dissolved oxygen depletion occurs when total phosphorus concentrations are greater than 10 µg/L, which is often used as an upper bound for oligotrophic conditions. A study of phosphorus and hypolimnetic oxygen demand lakes in British Columbia found that cold-water salmonid fisheries were protected with total phosphorus levels ranging from 5 to 15 µg/L (Nordin 1986).



- Whitefish and cisco are most abundant in a trophic state index (TSI) range of 30 to 40, which corresponds to total phosphorus levels of 6 to 12 µg/L.
- Typical concentrations of total phosphorus in Minnesota designated lake trout lakes is 9 to 16 µg/L. For the lakes exhibiting adequate refuge for lake trout, the summer average total phosphorus commonly ranged from 8 to 10 µg/L;
- The upper bound for total phosphorus concentrations sustaining lake trout is likely 15 µg/L.

Ultimately, phosphorus loading to LCO must be reduced to restore the water quality and biologic conditions in this unique ORW. The threat of negative impacts from climate change heightens this need.

Hydrodynamic modeling of mixing between LCO bays and basins and empirical modeling of hypolimnetic dissolved oxygen demand to support the proposed total phosphorus criterion for LCO are presented in Section 10.



10

Modeling to Support Proposed SSC

This section describes modeling approaches to support the proposed total phosphorus SSC for LCO of 10 µg/L. First, the approach used to assess improved biologic condition, as represented by hypolimnetic dissolved oxygen, is discussed. Second, the hydrodynamic model developed to predict the rate of mixing between the bays and basins of LCO is presented.

10.1 Assessment of Improved Biologic Condition

Based on the data presented in Section 7.2, the biologic condition of LCO is impaired due to hypolimnetic dissolved oxygen concentrations below 6 mg/L. Whitefish, which were shown in Section 5.2 to be the most sensitive cold-water species present in LCO, prefer to use the bottom waters of a lake. Therefore, an important aspect of evaluating biologic conditions in LCO relates to reductions in hypolimnetic oxygen demand with lower total phosphorus (TP) concentrations.

Chapra and Canale (1991) showed that hypolimnetic oxygen demand (HOD) varied across lakes as a function of $TP^{0.478}$. The following equation can be used to project HOD based on observed depletion rates and baseline and future TP concentrations:

$$HOD_{future} = HOD_{present} * (TP_{future}/TP_{present})^{0.478}$$

Where,

HOD_{future} = projected hypolimnetic oxygen demand, mg/L/d

$HOD_{present}$ = current hypolimnetic oxygen demand, mg/L/d

TP_{future} = desired future water column total phosphorus, µg/L

$TP_{present}$ = current water column total phosphorus, µg/L

As described in Section 7.2, profiles of temperature and dissolved oxygen were collected at seven LCO stations in 2013 (LCO 1 thru 6 and MB1; Figure 2). The profiles were inspected to identify measurements in the bottom waters of the hypolimnion where oxygen was clearly depleted, and average dissolved oxygen concentrations were calculated at these locations for each date and station. Rates of hypolimnetic oxygen demand were then determined using linear regression on the time series. R-squared values were high for each bay and basin and ranged from 0.83 to 0.99.

Using the equation above, the calculated current hypolimnetic dissolved oxygen rates, and current water column total phosphorus concentrations (as represented by seasonal means for the 2002 to 2013 period), future hypolimnetic oxygen demand was predicted for each bay and basin with a future condition of 10 µg/L total phosphorus in the water column. The percent decrease in future hypolimnetic oxygen demand was then calculated for each bay and basin.

As shown in Table 6, improvements in hypolimnetic oxygen demand are most striking in Musky Bay, where HOD is nearly cut in half.



Table 6. Present and future total phosphorus and hypolimnetic dissolved oxygen demand in LCO basins and bays.

Bay/Basin	TP _{present} (µg/L)	HOD _{present} (mg/L/d)	TP _{future} (µg/L)	HOD _{future} (mg/L/d)	Decrease in HOD (%)
Musky Bay	37.1	0.282	10	0.151	47%
Stuckey Bay	15.7	0.103	10	0.083	19%
West Basin	13.2	0.148	10	0.130	12%
Central Basin	9.8	0.114	10	0.115	-1%
East Basin	11	0.123	10	0.118	4%
Northeast Bay	10.9	0.07	10	0.067	4%

10.2 Hydrodynamic Modeling

A fine-scale hydrodynamic model of LCO was developed to directly predict the amount of mixing between bays and basins in support of the proposed SSC.

The hydrodynamic model was based upon the Environmental Fluid Dynamics Code (EFDC), a U.S. Environmental Protection Agency (EPA)-supported modeling framework. Application of the EFDC model consisted of the following steps:

- Development of a model grid
- Comparison of model predictions to surface temperature data
- Application of the model to define mixing between bays and basins

Development of the model grid consisted of digitizing the bathymetric map of LCO, then developing a curvilinear segmentation scheme that captured the variation of the bathymetry. The resulting grid has 2,125 cells horizontally; when applied in three-dimensional mode there are a total of 21,250 cells.

Once the model grid was established, EFDC was applied using observed 2012 climatic data (from Sawyer County Airport and the Rice Lake solar radiation site) as model inputs. Surface temperatures predicted by EFDC were successfully compared to observed data from multiple lake stations to demonstrate the reliability of model predictions.

The next step of EFDC application consisted of a dye tracer simulation to define mixing between bays and basins. The model was vertically condensed into two dimensions for computational purposes, and a slug of conservative dye (100 mg/L; ~500 million grams total) was entered into the model at Musky Bay on June 1. EFDC predicted the rate at which this dye spread throughout the rest of the lake over the remainder of the year. The volumes of Musky Bay and West basin are 4.9 and 39 million cubic meters, respectively.

Results from the dye simulation are provided in Figure 10, where predicted dye concentrations are given in two-week intervals. As seen in Figure 10, the concentration of the dye slug moving through West basin is between 11 and 22 mg/L after 10 weeks after dye release from Musky Bay.



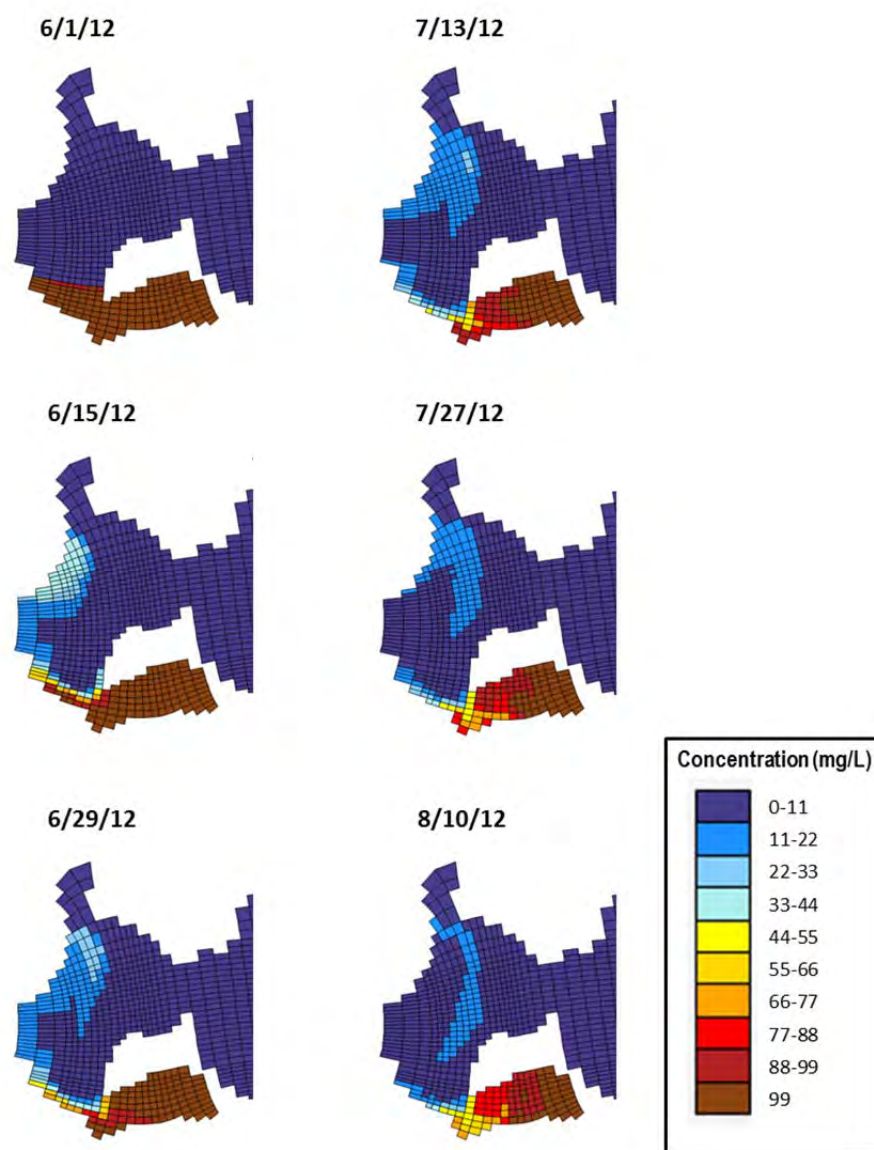


Figure 10. Predicted dye concentrations in LCO at two-week intervals following release of 100 mg/L in Musky Bay on June 1.

Figure 11 shows the time series of the predicted mass of the dye slug in Musky Bay and West basin as the percent of the mass of dye released. After one month, 38% of the dye slug has moved into West basin from Musky Bay. After two months, almost half (48%) of the dye mass has moved into West basin.

The hydrodynamic model clearly shows the influence of loads entering Musky Bay on West basin, and results support consideration of LCO as one integrated aquatic system.

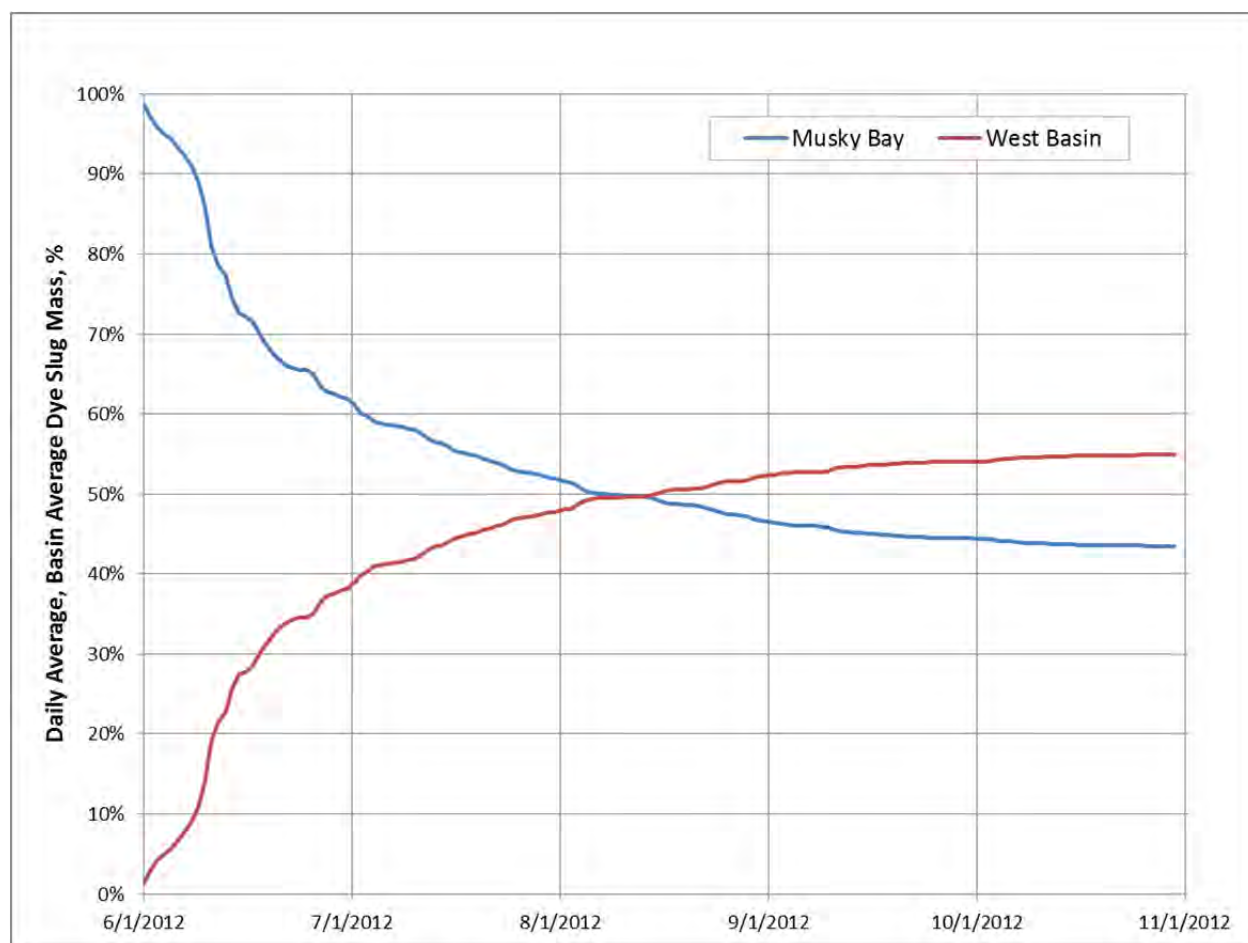


Figure 11. Predicted daily average mass of dye slug in Musky Bay and West basin (percent). Dye was released in Musky Bay at 100 mg/L on June 1.

11

References

- American Fisheries Society (AFS), 2003. Population Genetics: Principles and Applications in Fisheries. Eric Hallerum-Editor. AFS, Bethesda, Md. ; 471 pages.
- Birks, et al. 1990. Diatoms and pH Reconstruction. *Phil. Trans. R. Soc. Lond. B* 327, 263-278.
- Chapra, S.C. and R. P. Canale. 1991. Long-Term Phenomenological Model of Phosphorus and Oxygen For Stratified Lakes. *Wat. Res.* Vol. 25, No. 6, pp. 707-715.
<http://deepblue.lib.umich.edu/bitstream/handle/2027.42/29315/0000380.pdf?sequence=1>
- Fang X., S.R. Alam, L. Jiang, P. Jacobson ,D. Pereira and H. Stefan. 2010. Simulations of Cisco Fish Habitat in Minnesota Lakes Under Future Climate Scenarios. Project report No. 547 prepared by the University of Minnesota St. Anthony Falls Laboratory for the Minnesota Department of Natural Resources.
- Fitzgerald, et al. 2003. Nutrient, Trace-Element, and Ecological History of Musky Bay, Lac Courte Oreilles, Wisconsin, as Inferred from Sediment Cores. U.S. Geological Survey Water-Resources Investigations Report 02-4225.
- Garrison, Paul. 2014. Report on Sediment Core Analysis from Lac Courte Oreilles, Sawyer Co. WI Towards Estimating Historical Phosphorus Concentrations. Wisconsin Dept. of Natural Resources.
- Garrison, Paul. May 2014. Wisconsin Department of Natural Resources. Personal communication with Virginia Breidenbach.
- Garrison and LaLiberte, 2012. Paleoecological Study of Shell Lake, Washburn County. Wisconsin Department of Natural Resources, Bureau of Science Services.
- Harmony Environmental. 2007. Macrophyte Survey Musky Bay-Lac Courte Oreilles.
- Heiskary, Steven A. and C. Bruce Wilson. 2005. Minnesota Lake Water Quality Assessment Report: Developing Nutrient Criteria. Third Edition. Minnesota Pollution Control Agency.
- Heiskary, Steven and Bruce Wilson. 2008. Minnesota's Approach to Lake Nutrient Criteria Development. *Lake and Reservoir Management* 24:282-297, 2008
- Intergovernmental Panel on Climate Change (IPCC). 2013. Summary for Policymakers. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the fifth assessment report of the IPCC. Cambridge University, Cambridge.
- Jacobson P.C., H.G. Stefan and D.L. Pereira. 2010. Coldwater Fish Oxythermal Habitat in Minnesota Lakes: Influences Of Total Phosphorus, July Air Temperature, and Relative Depth. *Canadian Journal of Fisheries and Aquatic Sciences* 67(12), 2003-2013.
- Johnson, L. 1986. Population Dynamics of Stocked Adult Muskellunge (*Esox Masquinony*) in Lac Courte Oreilles, Wisconsin, 1961-77. Wisconsin Department of Natural Resources, Tech Bulletin No. 160; 12 pages.



Kampa, Jeff. January 2014. Wisconsin Department of Natural Resources. Personal communication with Frank Pratt.

National Oceanic and Atmospheric Agency (NOAA). 2013. NOAA Atlas 14 Precipitation-Frequency Atlas of the United States Volume 8 Version 2.0: Midwestern States (Colorado, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Oklahoma, South Dakota, Wisconsin). <http://hdsc.nws.noaa.gov/hdsc/pfds/index.html>

Palmer M.E., N.D. Yan and K.M. Somers. 2014. Climate Change Drives Coherent Trends in Physics and Oxygen Content in North American Lakes. *Climatic Change* doi:10.1007/s10584-014-1085-4

Pratt, F.B. 2007. Summary of Northern Pike Removal from Musky Bay, April 2007. Hayward Fishery Files. Hand-written; 1 page.

Pratt, Frank. 2013. Loss of Beneficial Uses, Musky Bay, Lac Courte Oreilles.

Pratt, Frank. May 2014. Personal communication with Virginia Breidenbach.

Pratt, F. B. and D. Neuswanger. 2006. Lac Courte Oreilles Fishery Plan. Wisconsin Department of Natural Resources; 18 pages.

Robertson D.M. and R.A. Ragotskie. 1990. Changes in the Thermal Structure of Moderate to Large Sized Lakes in Response to Changes in Air Temperature. *Aquatic Science* 52: 360-380.

Sharma S., M. Jake Vander Zanden, J.J. Magnuson and J. Lyons. 2011. Comparing Climate Change and Species Invasions as Drivers of Coldwater Fish Population Extirpations. *PLoS ONE* 6(8): e22906. doi: 10.1371/journal.pone.0022906.

Sloss, B.L. 2006. Genetic Analysis of Butternut Lake and Lac Courte Oreilles Muskellunge Populations. U.W. Stevens Point Coop. Fishery Res. Unit/ Molecular Conservation Genetics Lab, Oct. 2006 Update on Muskellunge Research in Wisconsin, 3 pages.

Sloss, B.L., R.P. Franckowiak, and E.L. Murphy. 2008. Development of New Micro-Satellite Loci and Multiplex Reactions for Muskellunge (*Esox masiquony*). *Molecular Ecology Resources*, 8: 811-13.

Stantec. 2012. 2012 Aquatic Plant Management Report for Lac Courte Oreilles. Cottage Grove, Wisconsin. Dec. 18, 2012 Report to COLA.

Tyrolt, Daniel D. 2011. Lac Courte Oreilles Lake Aquatic Plant Management Plan, Sawyer County, WI. WIBC: 2390800.

University of Wisconsin Extension (UW Extension). 2013. Aquatic Invasive Species Education Handbook. PDF file in www.uwex.edu. Chapter 7-Species Information.

Wilson, C. Bruce. 2010. Lac Courte Oreilles Economic Survey and Assessment. Prepared for the Wisconsin Department of Natural Resources under a Lake Management Grant to the Courte Oreilles Lakes Association.

Wilson, C. Bruce. 2011. Lac Courte Oreilles Lake Management Plan.

Wisconsin Administrative Code (WAC). 1993. Department of Natural Resources Chapter NR 102 Water Quality Standards for Surface Waters. <https://docs.legis.wisconsin.gov/code/archive/1993/449b/insert/nr102.pdf>.

Wisconsin Department of Natural Resources (WDNR). 2012. Wisconsin 2012 Consolidated Assessment and Listing Methodology (WisCALM) for Clean Water Act Section 305(b), 314, and 303(d) Integrated Reporting. Amended Version 1.



Wisconsin Department of Natural Resources. (2013). Wisconsin 2014 Consolidated Assessment and Listing Methodology (WisCALM). 2014. Clean Water Act Section 305(b), 314, and 303(3) Integrated Reporting. September 2013. <http://dnr.wi.gov/topic/surfacewater/documents/2014/2014WisCALM.pdf>

Wisconsin Department of Natural Resources. (2014). Site-Specific Criteria Framework for Wisconsin. Draft. April 15, 2014.

Wisconsin Initiative for Climate Change Impacts (WICCI). 2011. Wisconsin's Changing Climate: Impacts and Adaptations. http://www.wicci.wisc.edu/report/2011_WICCI-Report.pdf



Appendix C



Blank page



Loss of Beneficial Uses

Musky Bay, Lac Courte Oreilles

May 2013

By Frank Pratt, Fisheries Biologist



View of Lac Courte Oreille's Musky Bay with Central Bay in Upper Top.
Photo Credit: Steve Umland

Acknowledgments

Many thanks to all of my colleagues at Wisconsin DNR. Also special thanks to Gary Pulford, Bruce Wilson, and Dan Tyrolt for editing assistance.

Table of Contents

Table of Figures	2
Table of Tables	2
Executive Summary	3
Introduction	3
Information Sources	3
Background	3
Musky Bay Morphometric Characteristics.....	4
Musky Bay Sediment Characteristics.....	5
Muskellunge Spawning Habitat Oxygen Requirements	6
Musky Bay's Oxygen Depletion Rates.....	7
Winter-kill Incidence.....	10
Northern Pike Removal to Improve Muskellunge Spawning	11
WDNR Hayward Fisheries Survey Navigation Impairment	12
Curly Leaf Pondweed (CLP), an Aquatic Invasive Species	13
Summary	15
References	16

Figures

Figure 1: Winter Musky Bay Temperature and Dissolved Oxygen Concentration Profile for March 18, 2012.	7
Figure 2: Summer Musky Bay Temperature and Dissolved Oxygen Concentration Profile for June 15, 2012.....	8

Tables

Table 1: Select Morphometric Characteristics.....	5
Table 2: Critical Fisheries Dissolved Oxygen Concentrations	6
Table 3: Oxygen Depletion History in Musky Bay, 2003-2013, by Season and Depth Strata	9
Table 4: Musky Bay calculated oxygen depletion rates (2003-2012) based on oxygen profile data and estimated days for depletion from 9.0 mg/L to 2.0 and 1.0 mg/L.....	10
Table 5: Sawyer County Winter-kill Tabulation 1960-2013 from WDNR Hayward Fishery Files.....	11
Table 6: Tabulation of WDNR and GLIFWC fall electrofishing survey navigation impairment notations.	13
Table 7: Musky Bay aquatic plant survey summary following invasive introduction Curly Leaf Pondweed in 2005 and first treated in 2007. From Aquatic Plant Management Report (Stantec, 2011).	14

Executive Summary

This report summarizes stressors relating to the loss of fishable and recreational beneficial uses in Musky Bay based on examination of: (1) observed and estimated dissolved oxygen depletion rates ; (2) winterkill incidence ; (3) loss of key muskellunge spawning habitat; and (4) extensive aquatic plant growth, especially the exotic, curly leaf pondweed - all leading to seasonal loss of research and recreational navigation, fishing, and swimming.

Introduction

The term “impairment” describes the loss of swimmable and fishable beneficial uses caused by a variety of physical, chemical and habitat degradations affecting the biology and ecosystem function. At present Wisconsin DNR recognizes Musky Bay as impaired based on total phosphorus, professional judgment pertaining to community structure (atypical macrophytes) and the “overwhelming” number of public comments describing degradation (Johnson, 2012; WDNR, 2013). This report includes additional causal analyses of impairments found in Musky Bay of Lac Courte Oreilles that should be considered in future 303(d) listing processes.

Information Sources

Information assembled in this document was obtained from Wisconsin Department of Natural Resources (WDNR) Hayward Fishery Files (HFFs) and Lac Courte Oreilles Conservation Department (LCOCD) records. The LCOCD has maintained a long-term LCO monitoring program including temperature and oxygen profiles spanning the period 1996 through 2012. Quality assured data from the LCOCD monitoring program has been used to define Musky Bay thermal mixing patterns and dissolved oxygen depletion rates. Published oxygen requirements for sports fisheries survival and propagation have been used to evaluate Musky Bay conditions. Musky Bay fish-kills, tabulated by the WDNR are summarized and compared to Sawyer County lake winter fish-kills patterns. Fishery research notes on survey navigation during routine fall electro-fishing surveys, were also evaluated. These records may not have been fully assessed in previous WDNR WisCALM evaluations.

Background

Lac Courte Oreilles (LCO) is classed as a “two story” fishery, supporting both cold and warm water fish species). This lake draws thousands of visitors from Wisconsin, Minnesota, Illinois and states as far away as Hawaii (Wilson, 2010). LCO provides around 20,000 fishing trips per year, with a minimum value of at least \$700,000 per annum. Musky Bay accounts for about 12% of the total annual fishing effort – 2400 trips and \$75,000 per year (Pratt and Neuswanger, 2006). Historically, Musky Bay has been an important muskellunge spawning area for Lac Courte Oreilles (Johnson, 1986). The lake

had long been considered as a world-class muskellunge fishery. (Pratt and Neuswanger, 2006).

Prior to 2008, Musky Bay's fisheries were monitored ~ annually using standard WDNR Fisheries electro-shock surveying methods. The Governor Thompson Hatchery relied upon collection of walleye, northern pike, and up until very recently, muskellunge from Musky Bay, for regional fisheries propagation. However, no successful muskellunge spawning in Musky Bay has been documented since the early 1970s (Johnson, 1986).

The Fish Management Plan (FMP) for Lac Courte Oreilles (Pratt and Neuswanger, 2006), recognizes Musky Bay as fishery-impaired due to very poor muskellunge reproduction and recommends consideration of dredging to restore spawning habitat.

Northern pike have long been suspected as an additional limiting factor to sustainable muskellunge reproduction (Caplan, 1982, Johnson, 1986; Inskip, 1986). In the 2006 litigation, State of Wisconsin, et al vs. Zawistowski (as cited in Andersen, 2006) WDNR Fisheries staff testified that Musky Bay was impaired for muskellunge reproduction. At that time, it was difficult to distinguish the relative effects of competition/predation by northern pike from habitat degradation. Recent DNA studies (Sloss, 2006; Sloss et. al., 2008), coupled with population manipulation now offer additional inter-species insights.

In 2007, in a cooperative venture by WDNR and the LCO Band of Ojibwe, about 1700 spawning northern pike were removed from Musky Bay. (Only six mature muskellunge were captured, and released). At that time, removal and control of northern pike was viewed as a pilot control effort to enable muskellunge recruitment. However, despite removal of 60% of northern pike from Musky Bay, successful muskellunge reproduction was not observed there (Pratt, 2007).

Musky Bay Morphometric Characteristics

Musky Bay covers about 271 acres (about 5.4% of the lake) and is one of eight embayments subject to bay-to-bay mixing within the 5,030 acre Lac Courte Oreilles basin. As can be seen in Table1, Musky Bay is shallow with maximum and mean depths of 18 feet and 5.5 feet, respectively. Estimated water residence time for Musky Bay was relatively long (> 3 years). As such, it has less volume to dilute pollutant inflows and can be expected to be sensitive to external and internally generated pollutant loads. Musky Bay is a polymictic basin (Wilson, 2010) and subject to temporary thermal stratifications disrupted by storm-induced mixing events with LCO's West Bay. Periodic withdrawal and discharge from cranberry bogs, located along its southern shore, can amount to substantial portions of the Bay's total water volume (e.g. 89 acres of bogs times 10 bog flooding's per year times one foot average depth per bog).

Table 1: Select Morphometric Characteristics

Characteristic	Musky Bay (% lake total surface)	Main Lac Courte Oreilles
Surface area (acres)	271 (5.4%)	5039
Max depth (ft.)	18	90
Mean depth (ft.)	5.5 (Volume 1488 acre-feet)	32
Trophic state	Eutrophic	Oligotrophic/ Mesotrophic

Musky Bay Sediment Characteristics

Sediment characteristics are a critically important habitat component for fisheries such as muskellunge and have been the subject of considerable research (Barr (1991); Fitzpatrick et al. (2003), Garrison and Fitzgerald (2003), Zorn et. al. (1998), and James (2012). These studies have documented relatively recent (e.g. over the past 30-40 years) degradations of Musky Bay including highly reduced, nutrient rich, oxygen poor substrates. They also have documented a recent increase in diatoms indicative of algal mats (Garrison and Fitzgerald, 2003).

Critical dissolved oxygen concentration ranges are summarized in Table 2 according to fish species, life stage, habitat, and season based on information from Cristel (2009); Davis (1976); Dombeck (1986); WDNR Fisheries Handbook (2013); and Zorn et. al. (1998)). Fish stress has been noted at ambient oxygen concentrations less than 3.0 ppm that may trigger fish migration and stress to fisheries. At 2.0 ppm dissolved oxygen levels, the fish community is at moderate to severe risk, depending on the species. Oxygen less than 2.0 ppm at the top of the sediment, may make it unsuitable for survival and incubation of muskellunge eggs. At 1.0 ppm, all fish are severely stressed and some species will die. At 0.5 ppm, fish mortality is likely. Winterkills occur under ice conditions as the water layer has less than 1.0 ppm dissolved oxygen resulting in substantial mortality to resident fish populations. In Musky Bay this occurs about 20% of the winters which is a very high occurrence for this region.

Table 2: Critical Fisheries Dissolved Oxygen Concentrations

Oxygen -ppm	Habitat	Season	Species	Life Stage	Effect	Frequency
3.0	Bottom waters	Summer	All	All	Stress/movement	100%
	Water Column	Winter	Mu,WE,LMB	All	Incipient stress/movement	100%
2.0	Sediment	Spring	Mu	Eggs	Poor incubation/Mortality	100%
	Water Column	Winter	Mu,WE, LMB	All	Stress/Movement	100%
1.0	Water Column	Winter	Mu, WE,BC	All	Severe Stress/Movement/Mortality	30%
			NP,BC,BG		Stress/Movement	
0.5	Water Column	Winter	All	All	Mortality	20%

Species key: NP = northern pike; Mu = muskellunge; WE = walleye; BC = black crappie; LMB = largemouth bass . The frequency is an annual frequency of occurrence. For example winterkill at < 1.0 ppm likely to occur twice in a ten year period = 20%.

The WDNR Fisheries Management Handbook (2013) recognizes minimum oxygen levels as a critical long-term limiting factor to fisheries. Failure to meet management criteria indicates a sub-optimal at-risk fishery and stocking would not be considered cost-effective to maintain a long-term fishery. The Fisheries Management Handbook has established restrictions to fish stocking based on winterkill incidence including:

- Winterkill frequency of less than 20% of winters for bass and northern pike; and
- Winterkill frequency of less than 10% of winters for muskellunge and walleye.

Muskellunge Spawning Habitat Oxygen Requirements

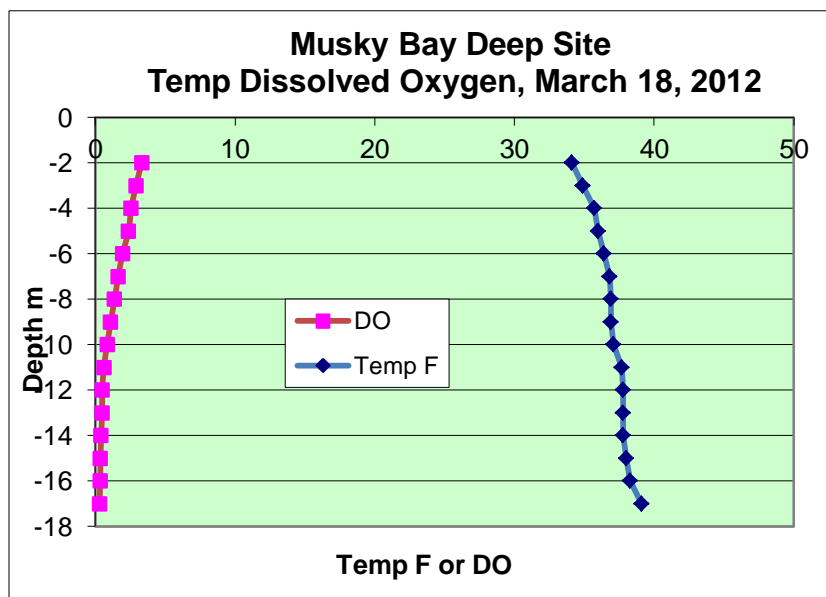
As cited by Pratt and Neuswanger (2006), the LCO genetic strain of muskellunge deposit their eggs on the lake bottom, where survival depends upon available oxygen along the sediment-water interface. Eutrophic conditions can severely limit oxygen availability at this critical life cycle stage as nutrient-enriched sediments cause increased oxygen depletion from the decay of organic matter. Poorly oxygenated sediments degrade spawning habitat as muskellunge eggs require more than 2 ppm oxygen concentrations for survival to fingerling stage. Nutrient-enriched sediments can also serve as a reservoir of phosphorus for pelagic and profundal plant growth that, in a positive feedback loop, generate increased production with resulting decomposition and greater oxygen depletion. Lastly, enriched sediments may serve as a fertile substrate for invasive species such as curly leaf pondweed which, through excessive growth generate further sediment-water interface oxygen oscillations.

Prior to 1970, Musky Bay was acknowledged as the major muskellunge spawning site for LCO (Johnson, 1986; Pratt and Neuswanger, 2006). Since that time, there has been no evidence of successful natural reproduction in Musky Bay. Muskellunge eggs are deposited on lake bottom surfaces while, northern pike eggs, by contrast, have an adhesive egg allowing them to cling to vegetation, well up in the oxygenated water column. In an in vivo experiment, Zorn et. al. (1998) found no muskellunge egg survival at oxygen levels at less than 2 ppm. (Table 2). Low sediment oxygen levels have been demonstrated by other investigations as a critical cause of muskellunge egg mortality (Dombeck et. al, 1984; Zorn et. al., 1998; Pratt and Neuswanger, 2006; Andersen, 2006).

Musky Bay's Oxygen Depletion Rates

Monitoring conducted by the LCOCD in 2012 defined very low winter oxygen concentrations at the Musky Bay deep site. By March 18, 2012, a peak oxygen value peak value of 3.2 mg/l was noted just below the ice with progressively lower concentrations at depth to a value of 0.3 mg/l above the bottom (Figure 1). The corresponding estimated oxygen depletion rate was quite high with an estimated value of 420 mg/day.

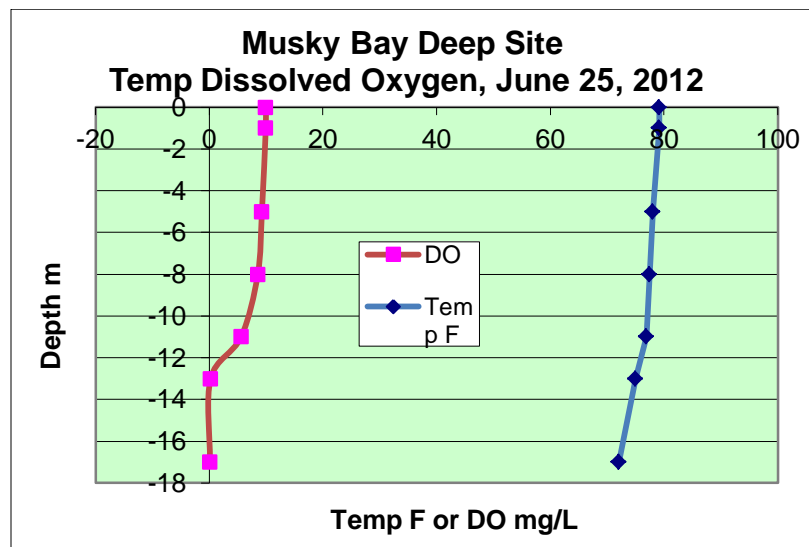
Figure 1: Winter Musky Bay Temperature and Dissolved Oxygen Concentration Profile for March 18, 2012.



With the seasonal progression, 2012 thermal stratification in Musky Bay had begun by June 15th. By June 25th, pronounced anoxia was observed as values ranged from 5.8 mg/l at the surface to 0.46 mg/l at the 17 foot depth level. This drop in oxygen concentration indicates a very high volumetric oxygen depletion rate in excess of 600 mg/m³/day.

Reviewing historical data, Musky Bay thermally stratifies about 2-4 times over the non-ice period, with a temporal thermal stratification coverage extending over about 60% of the summer. When summer stratification lasts more than 2 weeks, oxygen concentrations can be quickly depleted in bottom waters. In general terms, volumetric oxygen depletion rates of 500 mg/m³/day are extremely high values and have been noted for shallow productive reservoir systems (Walker, 1996) and not in oligotrophic-mesotrophic systems.

Figure 2: Summer Musky Bay Temperature and Dissolved Oxygen Concentration Profile for June 15, 2012.



Peak oxygen depletion rates were calculated from winter and summer oxygen profile data obtained by the LCOCD during 2003 – 2012 monitoring seasons at the Musky Bay deep site and summarized in Table 3. The relative magnitude of impacts to water column oxygen concentrations was more widespread during the ice covered months affecting most or all of the water column under ice.

Table 3: Oxygen Depletion History in Musky Bay, 2003-2013, by Season and Depth Strata.

Season	Depth	Depletion rate (mg/d)	D.O.	Frequency	Biological Impairment	Type Years	Percent of Musky Bay Volume**
Summer	10-18'	600	<2.0	All years, 1-4 times/summer over 1-4 weeks duration	Fish migrate, eggs suffocate, P recycled from sediments	2012 Fig. 1	3%
Winter	6-18'	420	<2.0	All years, most of winter	Fish migrate, eggs suffocate, P recycled from sediments	2012 Fig.2	50%
Winter	0-18'	340	<1.0	20% years, 4-8 weeks duration	Fish mortality or migration , eggs suffocate, P recycled from sediments	2003, 2009	100%

This summary from Heiskary and Wilson (2005), summarizes the relationship between oxygen depletion rates and lake phosphorus concentrations. [Note for comparison purposes, Musky Bay average concentrations have been in excess of 40 ug P/l.]

“Areal and volumetric measures of hypolimnetic oxygen depletion vary directly with total phosphorus concentrations as modified by lake morphometry (Walker 1979 & 1985b). For typical lakes, total phosphorus concentrations above 10-15 µg/l will usually result in the depletion of hypolimnetic oxygen concentrations. Our analysis of 74 minimally impacted Minnesota lakes tends to confirm this observation (Heiskary and Wilson, 1990). Nordin (1986) examined hypolimnetic oxygen depletion and phosphorus relationships from lakes in British Columbia. In this analysis, a range of total phosphorus concentrations between 5-15 µg/l was proposed for the protection of salmonid (coldwater) fisheries. It was noted that oxygen depletions generally began to occur when TP concentrations exceeded 10 µg/l, which is often used as an upper boundary for oligotrophic (Nurnberg, 1996). Expressed in other terms, an average summer chlorophyll-a of 2 µg/l and a corresponding summer-mean Secchi depth of 4.5 m and a AHOD of 0.25 g/m2/day also generally describe the transition from oligotrophy to mesotrophy (Rast and Lee, 1983).”

Winter-kill Incidence

Oxygen can be rapidly depleted under ice cover when photosynthetic oxygen production cannot keep up with aquatic respiration and decay of dead organic material in the sediment and the water column. The thickness and clarity of the ice, and the amount of snow cover, and the duration of ice cover are critically important. When there is insufficient light penetration for photosynthesis, oxygen concentrations may quickly decline. A further result of elevated dissolved oxygen depletion is the incidence of winter-kills.

Musky Bay is compared to other winter-kill lakes in Sawyer County, 1960 to 2013, based on documentation from the WDNR's HFF's. For comparison, winter kill data from Spring Lake is used to typify winterkill-prone productive lakes of the NW Wisconsin region. It is comparable to Musky Bay in size and drainage area, but with slightly higher average total phosphorus concentration (mean TP ~ 45).

In 2009, a winterkill occurred in Musky Bay about five (5) weeks into the ice cover period with a corresponding estimated mean daily oxygen depletion rate of 340 mg/day, which is typical of highly eutrophic, winterkill prone lakes (Charlton (1990), Mathias and Barcia (1979), Babin and Prepas (1984), Charlton (1990), Welch et. al.(1976), Moss and Scott(1961). Over the entire dissolved oxygen depletion rate averaged 190 mg/day and ranged from 40 to 690 mg/day. At a sustained depletion rate of 690 mg ppm/day, a fishery could become endangered (less than 2.0 mg/L) within about two weeks.

Table 4: Musky Bay calculated oxygen depletion rates (2003-2012) based on oxygen profile data and estimated days for depletion from 9.0 mg/L to 2.0 and 1.0 mg/L.

Mean Dissolved Oxygen Depletion Rate mg/day	Range (lowest to highest in mg/day)	Days to Endangerment (2.0 mg/L)	Days to Imperilment (1.0 mg/L or acute)
190	40 - 690	37 (10-175 days)	42 (12-200 days)

Historically, there has been a sharp decline in Sawyer County winter fish-kills from a peak of 35 incidences in the 1960-1979 time period to 3 noted from 2000-2012. Over the most recent years, Musky Bay has the greatest number of documented fish-kills, as tabulated by the WDNR's Hayward Fisheries Office, and accounts for about 2/3's of winterkills in Sawyer County tabulated since 1996. The increased incidence of fish-kills in Musky Bay is counter to the overall reduction in fish-kills tabulated from other Sawyer County lakes. It should be noted that Spring Lake was the only other winter-kill lake tabulated in 2012 in Sawyer County.

Table 5: Sawyer County Winter-kill Tabulation 1960-2013 from WDNR Hayward Fishery Files.

Period	County	Lakes	Winterkills	Winterkills/year	Trend
1960-1979	Sawyer	All County	35	1.75	
1980-2002			17	0.77	56% Decrease
2003-2013			3	0.30	58% Decrease
1960-1979		Spring	9	0.45	
1980-2002			6	0.27	40% Decrease
2003-2013			1	0.10	63% Decrease
1960-1979		Musky Bay	0	0	
1980-2002			0	0	
2003-2013			2	0.20	Large Increase

Northern Pike Removal to Improve Muskellunge Spawning

This examination is based on muskellunge research, with particular attention to the work of Zorn et. al. (1998) which specifically examined Musky Bay. Zorn attributed the loss of spawning muskellunge populations in Musky Bay to (1) increasing competition from northern pike and/or (2) habitat degradation. Northern pike may have competitive advantages over muskellunge due to (1) its gelatinous egg structure adhering to aquatic plants in the more oxygenated zones and (2) better low oxygen avoidance/survival. Adult northern pike are less likely to succumb to winterkill as they are more prone to low DO migration/avoidance than muskellunge (Davis , 1976; Table 2). Hence, removal of northern pike should improve the odds for muskellunge survival during the spawning period. This hypothesis was tested by the Wisconsin DNR Hayward office as they mechanically removed northern pike in April 2007 coupled with an examination of LCO muskellunge DNA genotypes by Sloss et al. (2006). If removal of northern pike aids muskellunge reproduction, then a strong species interaction is expected. If the genotype is stable over time then natural reproduction is occurring somewhere in LCO outside of Musky Bay (AFS, 2003)

The removal of 60% of the northern pike spawning population from Musky Bay in 2007 resulted in no discernible effect to either species, indicating, at best, a weak inter-species interaction. In this regard, the DNA study of Sloss (2006) and Sloss et. al. (2008) shows remarkable long-term genetic stability in the entire Lac Courte Oreilles, just not in Musky Bay. This indicates continued and successful natural reproduction, elsewhere in LCO (AFS, 2003). Northern pike are present throughout the lake, and therefore, their presence

cannot be the dominant factor in the decline of Musky Bay's muskellunge population. Based on this cumulative weight of evidence, impaired muskellunge recruitment may be due to degraded habitat. At present, Wisconsin DNR stocks about 1250 large fingerling muskellunge per year, at a cost of around \$13,000.

WDNR Hayward Fisheries Survey Navigation Impairment

Annual fall WDNR along with Great Lakes Indian Fish and Wildlife Commission (GLIFWC) surveys of Musky Bay have been an important assessment tool for tracking fisheries populations. Fishery survey field notes were used to gauge the relative ability to navigate within Musky Bay in performance of the surveys. A boom-shocker boat needs to operate close to shore, continuously, at 1-2 mph, at a speed comparable to a trolling fishing boat. Excess macrophyte growth can impede the survey. Survey notes were obtained from paper file survey notes from 1990 to 2010, to provide a measure of navigation impairment (Table 5). The WDNR Fisheries survey assessments may serve as a surrogate measure for typical fishing, recreational boating, and swimming accessibility based on interference from excess aquatic plants

Two levels of impairment are defined in Table 6: (1) survey made harder and less effective, but still completed; or (2) surveys cancelled, or not completed. The survey navigation data under-estimates the effects nuisance level aquatic plant growth has on the typical lake-user's navigation during the height of the growing season for curly leaf pondweed or *Cladophora* filamentous mats. By September, aquatic plant growth is usually on the decline. Hence, fall survey navigation impairment are an underestimate of summer peak growth conditions.

During the 1990s, 40% of the surveys were impeded to some extent by nuisance level aquatic plant growth, and 10% were cancelled. By 2000, cancellations had increased to 50%. After 2008, the Musky Bay sampling site was eliminated, totally, due to excessive aquatic plant growth. It is now likely that peak summer conditions are more restrictive, to general recreation (especially with peak curly leaf pondweed). Hence, Musky Bay is now severely impaired for typical fishing, recreational boating, and swimming during most of the summer.

Table 6: Tabulation of WDNR and GLIFWC fall electrofishing survey navigation impairment notations.

Survey Date	Agency	Investigator	Comments	Outcome
10-27-92	GLIFWC	White	"Dense vegetation"	Completed with some difficulty
09-05-96	GLIFWC	Quagon	"Heavy vegetation"	Completed with some difficulty
10-22-97	GLIFWC	Taylor	"A lot of ..vegetation. ..few fish"	Completed with some difficulty
9-02-98	GLIFWC	Taylor	"Heavy weeds"	Could not survey station
09-11-03	WDNR	Pratt/Warwick	"Not navigable"	Skipped station
09-18-08	WDNR	Pratt/Warwick	"Motor fouling"	Could not complete survey station
2009-2012	WDNR	Pratt/Wolter/Warwick	No longer feasible	Station permanently discontinued

Curly Leaf Pondweed (CLP), an Aquatic Invasive Species

The effect of CLP and its treatment regime on native plants in Musky Bay was documented by Stantec (2012) and summarized in Table 6 . From 2007 to 2011, macrophyte species diversity, richness and density decreased at all Musky Bay sites. During this time, Stantec found that 48% of the native species declined, 14% disappeared, and 65% remained stable, and only 7% increased. Jones (2010), and Heiskary and Valley (2010) found that CLP have similar negative impact on native species in Minnesota lakes.

Table 7: Musky Bay aquatic plant survey summary following invasive introduction Curly Leaf Pondweed in 2005 and first treated in 2007. From Aquatic Plant Management Report (Stantec, 2011).

Index	2007 Transects	2011 Transects	Indication
Community FQ1	35.0	30.9	Moderate loss
Simpson Diversity Index	0.84	0.75	Moderate loss
Native spp. /site	3.5	2.1	Significant loss
Species Richness	29	25	Significant loss
Species increased	NA	2	Moderate loss
Species decreased	NA	14	Moderate loss
Species stable	NA	19	Moderate loss
Species lost	NA	4	Significant loss

WisCALM (2012) does not recognize Aquatic Invasive Species (AIS), including curly leaf pondweed, as a biological impairment although its presence may profoundly affect native aquatic communities. As a result, curly leaf pondweed is typically treated to reduce its dominance by recurrent and long-term chemical measures. Literature citations have indicated that CLP can play as substantial role in increasing sediment oxygen depletion and also may affect internal loading of phosphorus. (Roesler, 2011; James, 2013; Heisarky and Valley, 2010; Waisel et. al., 1990, UW Extension 2013).

As stated by the UW Extension (2013): *“Curly leaf pondweed was the most severe nuisance aquatic plant in the Midwest until Eurasian Water Milfoil appeared. It forms dense surface mats that interfere with aquatic recreation.....tolerance for low light and low water temperature allow it to get a head start and out-compete native plants in the spring. In mid-summer when most aquatic plants are growing, curly leaf die offs may result in critically low oxygen. Furthermore, decaying plants can increase nutrients, which contribute to algae blooms, as well as create unpleasant, stinking messes.”*

Lastly, the WDNR and the Courte Lakes Association have expended considerable funds for the control of CLP to facilitate lake user navigation estimated to be about \$40,000 per year. The Wisconsin AIS program directly accounts for 6 million dollars of the entire 9 million

dollar Lake Grants budget. That degree of funding priority and institutional will seems to imply that AIS, in general, comprise a universally identified biological impairment.

Summary

This report summarizes biological impairments and associated loss of beneficial uses in Musky Bay and potential stressors based on examination of data collected from Lac Courte Oreilles and from the scientific literature.

1. Oxygen depletion has made Musky Bay the most winterkill prone water in Sawyer County in recent years, counter to county-wide patterns.
2. Elevated oxygen depletion rates do not provide suitable habitat conditions needed for successful muskellunge spawning in Musky Bay
3. Excess macrophyte growth impedes research, navigation, fishing, and swimming in Musky Bay.
4. CLP plays a key role in oxygen depletion, nutrient recycling, competition with native plants, and degraded research and recreation. It should be re-considered as a biological impairment in Musky Bay and elsewhere. It is recommended that AIS be considered a statewide biological impairment.
5. Degradation trends should play a more prominent role in ORW lake management such that early detection can aid in early rehabilitative actions.
6. The impairment history for Musky Bay strongly illustrates the need for early detection of degradation patterns coupled with rapid interventions by corrective actions by regulatory agencies as a part of antidegradation efforts. Otherwise, the viable alternative is passive observation of massive degradation as seen in Musky Bay followed by lengthy and expensive Total Maximum Daily Load studies.

References

American Fisheries Society, 2003. Population Genetics: Principles and Applications in Fisheries. Eric Hallerum-Editor. AFS, Bethesda, Md. ; 471 pages.

Anderson J.P., Circuit Court Judge. 2006. Findings of Fact and Law: State of Wi., et. Al. vs. William Zawistowski Jr.. Case 04CV75; 37 pages.

Barr Engineering. 1998. Lac Courte Oreilles Management Plan. Phase 1-Water Quality Study of Lac Courte Oreilles; Phase 2- Hydrologic and Phosphorous Budgets. Prepared for LCO Conservation Dept., COLA, and Wi. DNR.

Brewer, W.S., A.R. Abernathy, and M.J.B. Paynter. 1977. Oxygen consumption by freshwater sediments. Water Res., 11:471-73.

Caplan, D.L. 1982. An experimental study of interactions between young of the year pike (*Esox Lucius*) and muskellunge (*Esox masquinony*). M.S. Thesis. U Wi., Madison, Wi..

Charlton, M.N. 1990. Hypolimnion oxygen consumption in lakes: discussion of productivity and morphometry effects. Can. J. Fish. and Aquatic Sci., 37: 1531-1539.

Cristel, Paul. 2009. Report on winterkill in Musky Bay. LCO Conservation Dept. memo; 4 pages

Davis, J.C. 1976. Minimal dissolved oxygen requirements of aquatic life with emphasis on Canadian species: A review. JFRBC, 33 : 2295-2315.

Dombeck, M.P., B. W. Menzel, and P. Hinz. 1984. Muskellunge Spawning Habitat and Reproductive Success. TAFS 113: 205-216.

Dombeck, M. P., B. W. Menzel, and P.N. Hinz, 1986. Natural muskellunge reproduction in Midwestern lakes. In a Treatise on the biology and propagation of muskellunge in North America; 122-134. American Fisheries Society Special Publication 15; G.E. hall, editor; 372 pages.

Fitzpatrick F., P.J. Garrison, S.A. Fitzgerald, and J.F. Elder. 2003. Nutrient, trace element, and ecological history of Musky Bay, Lac Courte Oreilles, Wisconsin, as inferred from sediment cores. USGS Water Resources Investigations Report 02-4225; 141 pp.

Garrison, P.J., and S.A. Fitzgerald. 2005. The role of shore land development and commercial cranberry farming in a lake in Wisconsin,

Heisarky, S. and R.D. Valley. 2010. Curly-leaf pondweed trends and interrelationships with water quality. MN. DNR Invest. Report 558; 37 pages.

Inskip, P.D. 1986. Negative associations between abundances of muskellunge and northern pike: Evidence and possible explanations. In *Managing Muskies* (G. Hall, Ed.); AFS Spec. Pub. 15: 135-150.

James, W.F., A. DeChamps, N. Turyk, and P. McGinley. 2007. Importance of *Potamogeton crispus* decay to phosphorus budget of McGinnis Lake, Wisconsin. APCRP Technical Notes Collection. ERDC/TN APCRP-EA-15. Vicksburg, MS: US Army Corps Engineers Research and Development Center.

James, W.F. 2012. Sediment characteristics and diffusive phosphorus fluxes in Lac Courte Oreilles, Wisconsin. U.W.-Stout, Sustainability Sci. Inst.; 42 pages DRAFT

Johnson, L. 1986. Population dynamics of stocked adult muskellunge (*Esox masquinoy*) in Lac Courte Oreilles, Wisconsin, 1961-77. Wi. DNR, Tech Bulletin No. 160; 12 pages.

Jones, A.J. 2010. Effects of repeated early season herbicide treatment of curly leaf pondweed on native macrophyte assemblages in Minnesota lakes. U. MN. Digital Conservancy.

Kamke, K.K. 1989. Lake survey of Lac Courte Oreilles, 1988-89. WDNR internal report, Treaty Assessment Unit.

Moss, D.D. and D.C. Scott. 1961. Dissolved oxygen requirements of three species of fish. TAFS 90(4): 377-393.

Pratt, F. B. and D. Neuswanger. 2006. Lac Courte Oreilles Fishery Plan. Wi. DNR.; 18 pages.

Pratt, F. B. 1976. Comprehensive survey, Lac Courte Oreilles. Wi. DNR, Hayward Fishery Files. Internal report; 9 pages of text with attachments.

Pratt, F. B. 2003. Field survey notes- fall electrofishing, LCO monitoring stations. Wi. DNR. Hayward Fishery Files.

Pratt, F.B. 2008. Field survey notes-fall electrofishing, LCO monitoring stations. Wi. DNR. Hayward Fishery Files.

Pratt, F.B. 2007. Summary of northern pike removal from Musky Bay, April 2007. Hayward Fishery Files. Hand-written; 1 page.

Quagon, Sam. 1997. Field survey notes-GLIFWC fall survey of Lac Courte Oreilles. Hayward Fishery Files.

Stantec. 2012. 2012 Aquatic plant management report for Lac Courte Oreilles. Cottage Grove, Wi. Dec. 18, 2012 Report to COLA; 44 pages.

Sloss, B.L. 2006. Genetic analysis of Butternut Lake and Lac Courte Oreilles muskellunge populations. U.W. Stevens Point Coop. Fishery Res. Unit/ Molecular Conservation Genetics Lab, Oct. 2006 Update on Muskellunge Research in Wisconsin, 3 pages.

Sloss, B.L., R.P. Franckowiak, and E.L. Murphy. 2008. Development of new micro-satellite loci and multiplex reactions for muskellunge (*Esox masiquony*). Molecular Ecology Resources, 8: 811-13.

Taylor, Don. 1996. Field notes- GLIFWC fall survey of Lac Courte Oreilles. Hayward Fishery Files.

University of Wisconsin Extension. 2013. Aquatic invasive species education handbook. PDF file in www.uwex.edu. Chapter 7-Species Information.

Waisel, Y., J.J. Oerteli, and A. Stahel. 1990. The role of macrophytes in phosphorous turn-over: sources and sinks. Proceedings of 8th Symposium on Aquatic Weeds. EWRS: 234-248.

Same as US Dept. Interior et. al. HAS to be included later in whole lake discussions.

Welch, T.L. , E.P. Dillon, and A. Sreedharan. 1976. Factors affecting winter respiration in Ontario lakes. JFRBC, 33: 1809-1815.

White, Melvin. 1992. Field survey notes- GLIFWC fall electrofishing, Lac Courte Oreilles. Hayward Fishery Files.

Wilson, C. B. 2010. Lac Courte Oreilles Lake Management Plan. Prepared for the Lac Courte Oreilles (COLA). 52 pp.

Wisconsin DNR. 2012a. WisCALM. Latest update, currently subject to comment and revision.

Wisconsin DNR. 2013. Fisheries Management Handbook. Fish stocking guidelines. See above, Hunting Regs.

Zorn, S.A., T. L. Margenau, J. S. Diana, and C. J. Edwards 1998. The Influence of Spawning Habitat on Natural Reproduction of Muskellunge in Wisconsin. TAFS, 127: 995

Appendix D



Blank page





UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 5
77 WEST JACKSON BOULEVARD
CHICAGO, IL 60604-3590

08 MAR 2013

REPLY TO THE ATTENTION OF:

WS-15J

Mark Thayer
LCO Conservation Department Director
Lac Courte Oreilles Band of Lake Superior Chippewa
13394 W. Trepania Road
Hayward, Wisconsin 54843

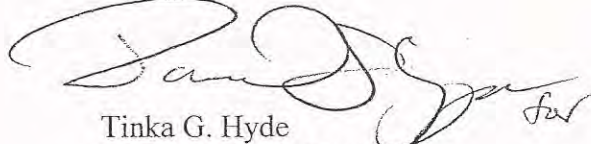
Subject: Quality Assurance Project Plan Approval
Grant Number I00E05801

Dear Mr. Thayer:

We are pleased to provide you with the approval of the Quality Assurance Project Plan (QAPP) for Water Quality Monitoring within the Lac Courte Oreilles Band Reservation. We would like to thank you and your staff in preparing and implementing the QAPP. Enclosed is a copy of the signed QAPP signature page for your records.

If you have questions regarding the QAPP approval, please contact Christine Urban, the Technical Contact at (312) 886-3493. For any grant related questions, please contact the Project Officer, Irene Cook at (312) 886-1823.

Sincerely,



Tinka G. Hyde
Director, Water Division

Enclosure

cc: Brett McConnell, LCO

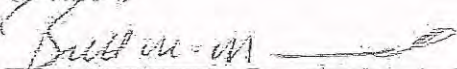
Quality Assurance Project Plan

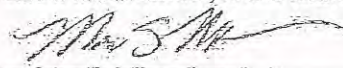
Prepared for the U.S. EPA

Clean Water Act Section 106
Water Quality Monitoring and Assessment Program
Lac Courte Oreilles Band of Lake Superior Chippewa
Grant# 100E05801-2
December 2012


The following parties have reviewed and approved the Quality Assurance Project Plan:

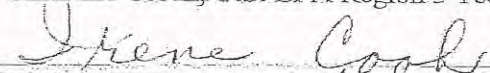
(Grantee)

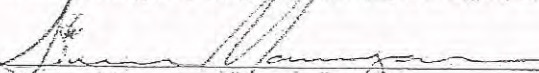
 Date 12/12/12
Brett McConnell, LCO Environmental Specialist, 106 Program Manager, QAPP Manager

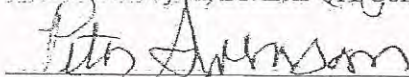
 Date 12/14/12
Mark Thayer, LCO Conservation Department Director

(U.S. EPA Region 5)

 Date 2/26/13
Christine Urban, U.S. EPA Region 5 Technical Contact

 Date 3/1/13
Irene Cook, 106 Project Officer, U.S. EPA Region 5 Water Division

 Date 02/26/2013
Simon Manoyan, Branch QA Contact, U.S. EPA Region 5 Water Division

 Date 2/26/13
Tinka G. Hyde, Water Division Director, U.S. EPA Region 5

**Quality Assurance Project Plan For
106 Water Quality Monitoring Project**

**Lac Courte Oreilles Reservation
Hayward, Wisconsin**

**Revision 2 for
Grant ID#I-00E05801 and I-00E57501**

Date: April 2011

**QAPP Prepared by: Brett M. McConnell, Environmental Specialist
LCO Conservation Department, 13394 W Trepania Rd. Bldg. 1 Hayward, WI 54843**

**Tribal Project Managers: Brett M. McConnell, Environmental Specialist \ Daniel
Tyrolt, LCO Environmental Engineer**

U.S. EPA Project Officer: Irene Cook

U.S. EPA Technical Contact: Christine Urban

U.S. EPA Acting Director, Region V Water Division: Tinka Hyde

TABLE OF CONTENTS	INTRODUCTION.....	4
SECTION ONE: PROJECT DESCRIPTION		4
1.1 SITE DESCRIPTION.....		4
1.1.1 Location and General Information.....		4
1.1.2 Site History.....		4
1.3 PROJECT OBJECTIVES.....		5
1.3.1 Problem Statement		5
1.3.2 Decision.....		6
1.3.3 Inputs to Decision		6
1.3.4 Study Boundaries		6
1.3.5 Decision Rule.....		7
1.3.6 Limits on Decision Errors.....		8
1.3.7 Design for Obtaining Data.....		9
1.4 PROJECT TARGET PARAMETERS and INTENDED DATA USAGE.....		9
1.5 SAMPLE NETWORK AND RATIONALE.....		10
1.6 PROJECT SCHEDULE		10
1.6.1 Anticipated Date of Project Mobilization		10
SECTION TWO: PROJECT ORGANIZATION AND RESPONSIBILITY		11
2.1 MANAGEMENT RESPONSIBILITIES		11
2.1.1 Field Responsibilities.....		11
2.1.2 Laboratory Responsibilities.....		11
2.1.3 Corrective Action		11
2.1.4 Project Organization Diagram.....		11
2.2 QUALITY ASSURANCE RESPONSIBILITIES		11
SECTION THREE: QUALITY ASSURANCE OBJECTIVES FOR MEASUREMENT		
DATA		13
3.1 DISCUSSION OF QUANTITATIVE QA OBJECTIVES		13
3.1.1 Precision		13
3.1.2 Completeness		13
3.1.3 Representativeness		13
3.1.4 Comparability		14
3.1.5 Accuracy		14
SECTION FOUR: SAMPLING PROCEDURES.....		15
4.1 SAMPLING ACTIVITY SUMMARY		15
4.2 SAMPLING EQUIPMENT AND PROCEDURES.....		15
4.2.1 YSI Multi-parameter Water Quality Meter & Hydrolab Datasonde		
4.....		15
4.2.2 Benthic Macro-invertebrate Sampling		15-16
4.2.3 Benthic Sample Inventory.....		16
4.2.4 Benthic Sample Processing.....		16-17
4.2.5 Sample Identification.....		17

4.2.6	Macro-invertebrate Data entry.....	17
4.3	Phytoplankton Sampling.....	18
4.4	Zooplankton Sampling	18
4.5	Total Suspended Solids (TSS).....	18
4.6	Total Phosphorus and Total Nitrogen Sampling	18
4.7	Diatom Analysis /Core Dating & Mercury Sediment Analysis.....	19-21
4.8	Cyanobacteria Microcystin-LR Sampling.....	21-22
4.3	DECONTAMINATION PROCEDURES	22
4.4	FIELD DUPLICATE COLLECTION	22
SECTION FIVE: CUSTODY PROCEDURES.....		23
5.1	FIELD CUSTODY PROCEDURES.....	23
5.1.1	Benthic Sampling Custody Procedures.....	23
5.2	LABORATORY CUSTODY PROCEDURES	23
5.2.1	Laboratory Sample Inventory	23
5.3	FINAL EVIDENCE FILE	24
SECTION SIX: CALIBRATION PROCEDURE AND FREQUENCY		24
6.1	FIELD INSTRUMENT CALIBRATION	24
SECTION SEVEN: ANALYTICAL PROCEDURES		25
7.1	FIELD ANALYTICAL PROCEDURES	25
7.2	LABORATORY ANALYTICAL PROCEDURES.....	25
7.2.1	Benthic Sample Processing.....	25-26
7.2.2	Macro-Invertebrate Sample Identification.....	26
7.2.3	Macro-invertebrate Data Entry.....	26
7.2.4	Phytoplankton Sample Processing and Identification.....	26
7.2.5	Zooplankton Sample Processing and Identification	27-28
7.2.6	TSS Sample Processing (NRRI).....	28-30
7.2.7	Total Phosphorus and Total Nitrogen Analytical Procedures.....	30
7.2.8	Sediment Diatom Methods	30
7.2.9	Cyanobacteria Toxin Analysis.....	30
SECTION EIGHT: INTERNAL QUALITY CONTROL CHECKS		31
8.1	FIELD QUALITY CONTROL CHECKS.....	31
8.2	LABORATORY QUALITY CONTROL CHECKS.....	31
SECTION NINE: DATA REDUCTION, VALIDATION AND REPORTING		31
9.1	DATA REDUCTION	31
9.1.1	Field Data Reduction.....	31
9.2	DATA VALIDATION.....	31
9.3	DATA REPORTING	31
SECTION TEN: PERFORMANCE AND SYSTEM AUDITS		31
10.1	FIELD PERFORMANCE AND SYSTEM AUDITS.....	31

SECTION ELEVEN: PREVENTATIVE MAINTENANCE	32
11.1 FIELD INSTRUMENT PREVENTATIVE MAINTENANCE	32
SECTION TWELVE: DATA QUALITY ASSESSMENT	32
SECTION THIRTEEN: CORRECTIVE ACTION	32
13.1 FIELD CORRECTIVE ACTION.....	32
SECTION FOURTEEN: QUALITY ASSURANCE REPORTS TO MANAGEMENT	32

Distribution List:

Dan Cozza, EPA Region Five Program Officer, Chicago
Christine Urban, EPA Region 5 Technical Contact
Mark Thayer, LCO Conservation Department Director
Dan Tyrolt & Brett McConnell LCO Environmental Department
Tinka Hyde, Director, USEPA Region Five-Water Division
Kris Goodwill, Attorney, LCO Tribal Government

Tables

Table 1 Surface Water Monitoring Locations/Parameters-Lakes

Table 2 Surface Water Monitoring Locations/Parameters-Rivers, Streams

Figures

Figure 1 Location of the Lac Courte Oreilles Reservation

Figure 2 USGS Gaging Stations in the Chippewa River Basin

Figure 3 Project Task Bar Chart and Associated Time Frames

Figure 4 LCO Water Quality Project Organization Diagram

Appendices

APPENDIX A-NRRI QA/QC Program Manual

APPENDIX B- YSI Multi-parameter Meter Calibration and Maintenance

Procedures

APPENDIX C-Cyanotoxin Microcystin ELISA Method

APPENDIX D-Sediment Diatom Methods

INTRODUCTION

This Quality Assurance Project Plan (QAPP) describes the procedures for water quality monitoring regarding the EPA Section 106 Grant Work Plan for the Lac Courte Oreilles (LCO) Reservation. The purpose of this project is to gather information on the quality of surface water found on LCO Reservation rivers, streams, and inland lakes. Since the last approved LCO QAPP, certain water quality parameters have been added to the program. All QA/QC information can be found in this document.

Water quality information gathered from this project will be used to determine water quality management needs. Results from the project will support the LCO Water Monitoring Database and will allow for reliable trend analysis in the future.

SECTION ONE: PROJECT DESCRIPTION

1.1 SITE DESCRIPTION

1.1.1 Location and General Information

The 76,464-acre Lac Courte Oreilles Reservation is located in west-central Sawyer County in Northern Wisconsin (see Figure 1). The Reservation is about 60 miles southeast of Duluth, MN, 150 miles north of Minneapolis, MN and the small town of Hayward, WI is six miles from the northwest corner of the Reservation.

According to the 2000 U.S. Census Bureau, there are approximately 2,900 people living within the Reservation boundaries and off-Reservation trust lands. Of the 2,900 individuals, roughly 74% are American Indian. There are currently 30 sub-communities spread out across the Reservation. The majority of these communities are located within a few miles of the main infrastructure of the Reservation. Other communities like Signor, New Post and Six Mile are more rural.

The LCO Reservation is a water rich environment located entirely within the Upper Chippewa Watershed (see Figure 2). Twenty-five lakes (including six that form part of the Chippewa Flowage) and forty-three miles of rivers and streams are found on the Reservation, and over 7,500 acres of the Reservation are classified as wetlands.

The largest lake found on the LCO Reservation is the Chippewa Flowage which is an impoundment of the East and West forks of the Chippewa River. The Chippewa Flowage has a surface area of over 15,300 acres and a maximum depth of 92 feet, which makes it Wisconsin's third largest lake.

1.1.2 Site History

Baseline water quality data has been gathered under the EPA 106 program for the past several

years on the Lac Courte Oreilles Reservation. Virtually all of the surface waters of the Reservation have been monitored in some capacity for the following parameters: total phosphorus, water clarity, chl. a, phytoplankton, zooplankton, macro-invertebrates and invasive species monitoring. This QAPP covers all the SOP=s pertaining to these activities and others which have been added to the new work plan.

1.3 PROJECT OBJECTIVES

1.3.1 Problem Statement

The state of Wisconsin designates the Chippewa Flowage and the majority of the waters on the Reservation as outstanding water resources. Compared to lakes in the Southern region of the state this may be the case, but it is the feeling of the LCO Tribal Council and the LCO Conservation Department (LCOCD) that surface water found on the LCO Reservation is being degraded due to non-point sources from new development, damaged septic systems, increased impervious surfaces, cranberry farming, lack of shoreline protection and heavy recreational traffic.

The LCOCD is also concerned with the influx of potentially harmful invasive species found on the Reservation which include Eurasian Water Milfoil (*Myriophyllum spicatum*), Purple Loosestrife (*Lythrum Salicaria*), Curly Leaf Pondweed (*Potamogeton Crispus*), and Zebra Mussels (*Dreissena polymorpha*), and the threat of Viral Hemorrhagic Septicemia (VHS) on certain fish species. Continual monitoring and treatment of these invasive species is vital towards protecting the integrity of Reservation waters.

Effluent discharged from cranberry marshes adjacent to Musky Bay on Big Lac Courte Oreilles Lake continues to be a major problem. Sample results throughout the ice-up period, particularly discharge periods, continue to show elevated nutrient levels compared to other bays and basins in the lake. Total phosphorus levels of over 1,000 ppb have been observed, and the LCOCD feels strongly that cranberry nutrient loads are having a direct effect on the density and diversity of plant growth within the bay.

The LCO Tribe relies heavily on the subsistence of fish from local waters in their diet. Fish advisories are in affect to some degree on all Reservation lakes.

In order for the LCOCD to determine water quality trends, scientific data must continue to be gathered. What is the basic water quality of LCO Reservation lakes and streams over the next five years? This project will monitor and collect data on surface water found on the Reservation, and use that data to analyze water quality trends and identify polluted waters.

Data gathered from this project will be analyzed and modeled by the Project Managers. LCOCD Water Resource Technicians will be responsible for the water monitoring procedures, data

gathering and other project services.

1.3.2 Decision

The LCOCD will determine whether there is cause for concern regarding the effects of increased development, invasive species, cranberry farming, increased impervious surfaces and heavy recreational traffic on the surface waters of the Reservation. Water quality parameters will be used as indicators that may prescribe for a more comprehensive study on a certain water body in the future. If the water quality is found to be degraded, lake/stream management plans will be developed to protect the integrity of that water body. If the water quality is found not to be degraded, then no further action will be taken at that time.

1.3.3 Inputs to Decision

This plan includes for the monitoring of the following parameters for Reservation water bodies: dissolved oxygen, pH, total dissolved solids, temperature, water clarity, specific conductance, Microcystin-LR sampling, diatom assemblage and core dating, total nitrogen, total phosphorus, total suspended solids, chl. *a*, and mercury sediment analysis. Most all rivers, lakes, and streams found on the Reservation will be monitored.

Point source discharges within the Reservation boundaries will continue to be inventoried using the Reservation's Global Positioning System and mapped with GIS. All off-reservation point sources discharging to receiving waters flowing onto the Reservation, or immediately adjacent to it, will be identified and mapped as well. See Attachments for all GIS Maps of sample sites routinely monitored in the 106 Program.

A year-end report will be prepared indicating the trends observed in water quality for that year with recommendations for sampling and monitoring for the next year. The LCOCD routinely conducts statistical analysis to determine seasonal trends, and water quality trends over time. A comprehensive Water Quality Assessment Report will be completed every 2 years as per EPA grant guidelines.

1.3.4 Study Boundaries

Profiles of the water quality parameters will be recorded for each water body at various locations throughout the lake or stream. Tables 1&2 provide the names of the lakes and streams to be monitored along with their location, number of monitoring sites and the surface water monitoring parameters.

Some potential constraints or obstacles that may possibly interfere with the study are: extreme weather conditions on the scheduled sampling date, mechanical difficulties, or the inability to gain access to the site due to poor landing conditions.

1.3.5 Decision Rule

One of the LCOCD=s main water quality concerns is the negative effects cranberry farming is having on the water quality of certain lakes within the Reservation borders. Thermal pollution, nutrient loading and dissolved oxygen fluctuations due to discharges are threatening ecosystems and negatively impacting crucial spawning habitat, and littoral zone complexes. Water quality monitoring must continue, along with surveying and identification of invasive species in the area.

Monitoring dissolved oxygen levels in Reservation trout streams must continue. **If DO levels drop below 7 mg/l in trout streams, investigative procedures will be taken to determine if proper agricultural practices (mainly forestry) are being conducted, or if nuisance beaver problems are occurring.**

Invasive species in certain lakes have had a direct impact on habitat, and natural spawning areas. The LCOCD, along with the LCO Community College and local lake groups, have been very pro-active towards mapping and monitoring Eurasian Milfoil, Curly-Leaf Pondweed and Purple Loosestrife coverage within or nexus to Reservation Borders/water bodies. **If certain invasive species are detected, and pose a significant risk to the resource, then control methods will be explored, and treatment will be considered.**

If total phosphorus levels reach the eutrophic or hyper-eutrophic range, management plans will be devised to determine the cause of the impact.

Monitoring Total Suspended Solids has begun on several Reservation streams. Total suspended solid levels represent the weight of filtered particulate material in water. Sources of this solid matter may include both inorganic and organic material from soil or stream bank erosion, decaying plant matter, algae, and wastewater discharges. In general, the concentration of TSS increases with increasing river flow due to erosional processes and bed sediment re-suspension. **Ranges of median concentrations of TSS for rivers and streams will be developed based upon data gathered in our baseline monitoring program. Once ranges are established, and if/when levels fall outside these pre-determined ranges, investigatory measures will be taken to determine whether the cause is from high flow rates, soil erosion, beaver problems, urban runoff, wastewater and septic system effluent, or other means.**

If *microcystin*-LR levels are found above 1 ug/L (drinking water guidance standard from WHO), then the LCOCD will construct boat landing signs, or provide educational materials to the public about health concerns associated with the toxin.

Water clarity (secchi disc), total phosphorus, and chl. a monitoring is used to determine trophic status for each reservation lake. **Trend analysis is performed annually for each water body. If trophic status trends start to deteriorate, then management plans will be developed for**

each respective water body to improve water quality.

In the future, if trend analysis of the other study parameters indicate noticeable environmental problems, management plans will be developed to correct the problem. Management plans will also be developed to reduce the impacts of point-source discharges and non-point source pollution on Reservation resources.

If benthic macro-invertebrate sampling occurs, the LCOCD will follow all SOPS for sampling and work with the Natural Resources Research Institute (NRRI) in Duluth, MN. All lab and sampling protocols can be found in the attachments.

Diatom analysis and core dating will provide historic information to the LCOCD, identifying periods of natural and cultural disturbances in the ecosystem. Data gathered from this sampling regime will be used as a reference tool towards educating riparian owners and lake association groups about water quality.

1.3.6 Limits on Decision Errors

In order to specify tolerable limits on decision errors, the errors must be identified and a null hypothesis must be chosen. Both types of decision errors must be defined and the true nature for each must be established. The LCOCD has determined that the two decision errors are (i) deciding that the water quality of LCO=s surface waters is degrading when it truly is not, and (ii) deciding that the water quality of LCO=s surface waters is not degrading when it truly is. The true state of nature for decision error (i) is that the surface water quality is not degrading. The true state of nature for decision error (ii) is that the surface water quality is degrading. The consequences of deciding that the surface water is degrading when it truly is not will be slight because the ability to generate data by monitoring the resource is vital in determining future surface water degradation. The consequences of deciding that the LCO=s surface waters are not being degraded when they truly are will be that the resource does not receive adequate protection from contamination sources. The LCOCD has concluded that decision error (ii) has the more severe consequences since the risk of surface water degradation clearly outweighs any type of risk from the surface waters not being degraded at this time.

Therefore, the baseline condition or null hypothesis (H_0) is Awater quality of LCO=s surface waters indicates degradation.@ The alternative hypothesis (H_a) is Awater quality of LCO=s surface waters does not indicate degradation.@ The more serious error, then, would be the false positive. The errors are something the LCOCD is willing to accept when making decisions based upon the outcome of the study.

The sampling design for this project was constructed by the LCOCD which is based upon previous knowledge of the water resources of the Reservation, and is in accordance with the sample design

outlined in the EPA's A Lake and Reservoir Restoration Guidance Manual@ (U.S. EPA, 1990). The sampling plan was designed to develop a formidable and accurate data collection process. The LCOCD will also be conducting statistical analysis of the project parameters in comparison to similar reference sites.

1.3.7 Design for Obtaining Data

The sample design for this project was carefully constructed to provide the most resource-effective data collection process possible. Sample site locations were based upon the above objectives and concerns; the sample design includes lakes, rivers and streams located on the Reservation.

Surface water monitoring locations can be found in Tables 1&2. Monitoring for DO in the winter months may occur on lakes found on the Reservation.

1.4 PROJECT TARGET PARAMETERS and INTENDED DATA USAGE

This plan includes for the monitoring of the following parameters for all Reservation water bodies:

- < dissolved oxygen,
- < water clarity,
- < pH,
- < total dissolved solids,
- < temperature,
- < specific conductance,
- < Microcystin-LR,
- < diatom assemblage and core dating,
- < total nitrogen,
- < total phosphorus,

- < total suspended solids,
- < chl. a, and
- < mercury sediment analysis.

Profiles of these parameters will be recorded for each water body at various locations throughout the lake or stream. Intended data usages of these parameters over time will allow for reliable trend analysis of the background water quality data.

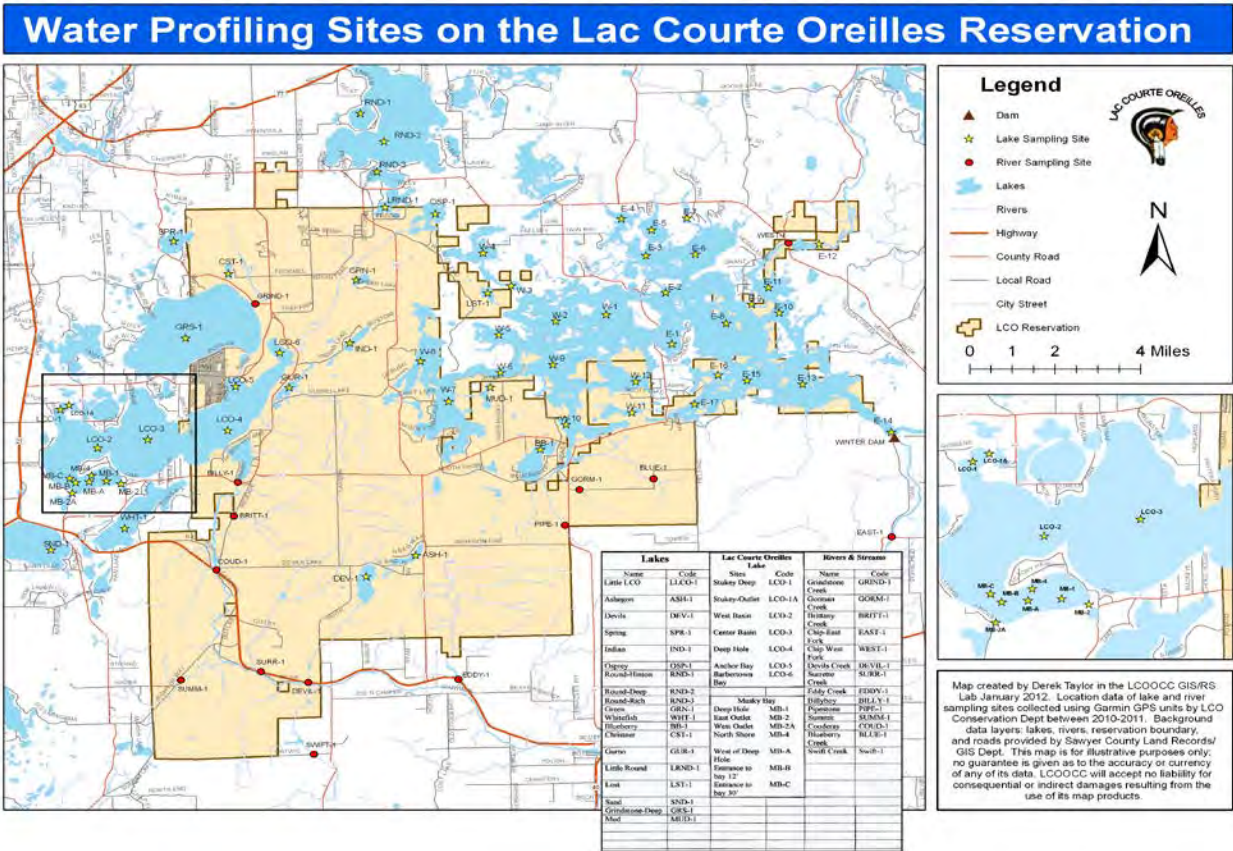
Diatom assemblage and core dating will be studied to understand how each lake on the reservation has changed over time. The central questions are: what were the past conditions of the lake, did the conditions of the lake change, when did this occur, and what were the causes? Reconstruction of historical diatom assemblages through analysis of sediment cores can be useful for determining historical changes in nutrient outputs. Diatoms, a diverse and usually abundant type of algae that possess siliceous cell walls, are especially useful in sediment-core analysis because they are ecologically diverse and well preserved in sediments; moreover, the ranges of favorable environmental conditions are known for several species.

Mercury sediment analysis is being sampled to understand concentrations of mercury for selected lakes. Are some reservation lakes more susceptible to mercury in fish tissue? Limited data has been gathered on certain reservation lakes from the Great Lakes Fish and Wildlife Service (GLIFWC) in recent years. Data from this study will help supplement those findings and provide important information to LCO tribal members.

Accurate background water quality data is also essential in order for the Reservation to develop and implement its own water quality standards and criteria for the Reservation. The development and enforcement of these standards will help to maintain the necessary water quality of tribal waters needed for subsistence fishing, gathering and ricing.

1.5 SAMPLE NETWORK AND RATIONALE

The sampling locations and depths for analyses are associated directly with the properties of the lake. For example, in a lake that is mostly shallow and almost round (Gurno Lake), a single station over the deepest point is adequate. In deep, stratified lakes (Grindstone and Lac Courte Oreilles) several sample stations will be used to monitor the deepest part of the lake, deep basins, point sources, and prominent bays. Rivers, streams and creeks found on the Reservation will be monitored monthly in the ice-free period as well. Current sampling sites chosen were due to ease of access and proximity to roads/crossings.



Lake Sample Sites			
Site Code	Site Description/Rationale	Lat/Long	On/Off Res
LLCO-1	Little LCO Lake-Deep Hole	N45 54.785/W091 23.463	Res
ASH-1	Ashegon Lake-Deep Hole	N45 50.723/W091 18.621	Res
DEV-1	Devils Lake-Middle	N45 50.191/W091 20.099	Res
SPR-1	Spring Lake-Deep Hole	N45 58.236/W091 25.421	Nexus
IND-1	Indian Lake-Middle	N45 55.756/W091 20.374	Res
OSP-1	Osprey Lake-Deep Hole	N45 58.768/W091 17.781	Res
RND-1	Round Lake-Hinton Bay Deep Hole	N46 01.172/W091 19.905	Nexus
RND-2	Round Lake-Deep Hole	N46 00.499/W091 19.233	Nexus
RND-3	Round Lake-Richardson's Bay Entrance	N45 59.786/W091 19.456	Nexus
GRN-1	Green Lake-Middle	N45 57.225/W091 20.167	Res
WHT-1	Whitefish Lake-Deep Hole	N45 51.482/W091 27.050	Nexus
BB-1	Blueberry Lake-Deep Hole	N45 53.165/W091 14.888	Res
CST-1	Christner Lake-Deep Hole	N45 57.442/W091 23.863	Res
GUR-1	Gurno Lake-Deep Hole	N45 54.710/W091 22.188	Res
LRND-1	Little Round Lake-Deep Hole	N45 58.947/W091 19.246	Res
LST-1	Lost Lake-Middle	N45 56.890/W091 16.339	Res
SND-1	Sand Lake-Deep Hole	N45 50.980/W091 29.211	Nexus
GRS-1	Grindstone Lake-Deep Hole	N45 55.903/W091 25.166	Nexus
GRSCR-1	Grindstone Lake-West Cranberry Outlet	N/A	Nexus
GRSCR-2	Grindstone Lake-East Cranberry Outlet	N/A	Nexus
MB-1	Musky Bay-Deep Hole	N45 52.607/W091 27.548	Nexus
MB-2	Musky Bay-East Cranberry Outlet		Nexus
MB-2A	Musky Bay-West Cranberry Outlet		Nexus
MB-4	Musky Bay North Shoreline	N45 52.737/W091 27.987	Nexus
MB-A	Musky Bay-West of Deep Hole	N45 52.592/W091 28.052	Nexus
MB-B	Musky Bay-Entrance 12'	N45 52.578/W091 28.456	Nexus
MB-C	Musky Bay-Entrance 30'	N45 52.682/W091 28.618	Nexus
MB-2A W	Musky Bay approx. 25 yds. East of cran. Outlet (wetland outlet)		Nexus
LCO-1B	Lac Courte Oreilles Lake-Bridge Outlet under Hwy. KK		Nexus
LCO-1	Lac Courte Oreilles Lake-Stukey Bay Deep Hole	N45 54.334/W091 28.883	Nexus
LCO-1A	Lac Courte Oreilles Lake-Stukey Bay Cranberry Outlet	N45 54.334/W091 28.689	Nexus
LCO-2	Lac Courte Oreilles Lake-West Basin Deep Hole	N45 53.376/W091 27.811	Nexus
LCO-3	Lac Courte Oreilles Lake-Center Basin	N45 53.424/W091 26.436	Nexus
LCO-4	Lac Courte Oreilles Lake Deep Hole	N45 53.862/W091 23.822	Res
LCO-5	Lac Courte Oreilles Lake-Anchorage Bay	N45 54.785/W091 23.710	Res
LCO-6	Lac Courte Oreilles Lake-Barbertown Bay	N45 55.555/W091 22.364	Res
LCO-Cran	Lac Courte Oreilles Lake-Point of Pines Cranberry Outlet-Surface	N/A	Nexus

Rivers/Streams Monitoring Sites			
Site Code	Site Description/Rationale	Lat/Long	On/Off Res.
GRIND-1	Grindstone Creek Hwy E Culvert	N45.94529/W091.38503	Res.
GORM-1	Gorman Creek-Blueberry Fire Lane	N45.87003/W091.22982	Res.
BRITT-1	Brittany Creek-Reserve Rd. Culvert	N45.86193/W091.39792	Res.
EAST-1	Chippewa River East Fork-HWY B Bridge	N45.90446/W091.04226	Nexus
WEST-1	Chippewa River West Fork-HWY B Bridge	N45.96535/W091.12498	Res.
DEVIL-1	Devils Creek-Hwy 27 Crossing	N45.79618/W091.36353	Res.
SURR-1	Surette Creek-Hwy 27 Crossing	N45.79793/W091.42523	Res.
EDDY-1	Eddy Creek-Hwy 27 Crossing	N45.79545/W091.28987	Nexus
BILLY-1	BillyBoy Flowage-Hwy E Bridge	N45.87537/W091.39575	Res.
PIPE-1	Pipestone Creek-Hwy H Crossing	N45.85170/W091.23524	Res.
SUMM-1	Summit Creek-Right of Way Rd. Crossing	N45.79796/W091.42558	Res.
COUD-1	Couderay River-Behind Historical Marker off Hwy 27	N45.83952/W091.40678	Res.
BLUE-1	Blueberry Creek-Blueberry Fire Lane Crossing	N45.87373/W091.19365	Res.
GRS-O	Grindstone Lake Outlet	N/A	Res.
GRS-I	Grindstone Lake Inlet	N/A	Res.

Lake Sample Sites			
Site Code	Site Description/Rationale	Lat/Long	On/Off Res.
E4	Chippewa Flowage-Musky Bay	45.969288/-91.208668	Nexus
E5	Chippewa Flowage-Moss Creek Bottoms	45.961204/-91.194377	Nexus
E6	Chippewa Flowage-Popple Island Deep Hole	45.960488/-91.170130	Nexus
E8	Chippewa Flowage-River Channel East of Pete's Bar	N45 53.241/W091 22.554	Nexus
E9	Chippewa Flowage-John James Lake Deep Hole	N45 53.194/W091 22.524	Res.
E11	Chippewa Flowage-Moore's Bay	N45 53.092/W091 22.285	Res.
E13	Chippewa Flowage-North of Cranberry Bars Deep Hole	45.910048/-91.121721	Res.
E14	Chippewa Flowage-Winter Dam Deep Hole	45.889680/-91.077218	Nexus
E16	Chippewa Flowage-Moonshine Lake Deep Hole	45.913511/-91.161246	Res.
E17	Chippewa Flowage-Pokegema Lake	45.904703/-91.169572	Res.
W1	Chippewa Flowage-Eagle Island Deep Hole	N/A	Nexus
W3	Chippewa Flowage-Crane Creek Channel	45.950762/-91.260724	Nexus
W4	Chippewa Flowage-Crane Lake Deep Hole	45.96374/-91.274285	Nexus
W6	Chippewa Flowage-Tyner Lake Deep Hole	45.915960/-91.266818	Nexus
W7	Chippewa Flowage-Chief Lake Deep Hole	45.901627/-91.289949	Res.
W8	Chippewa Flowage-Squaw Bay	45.921214/-91.304584	Res.
W9	Chippewa Flowage-Rice Lake basin	45.920886/-91.240940	Nexus
W11	Chippewa Flowage-Two Boys Lake Deep Hole	45.899536/-91.203089	Res.

SECTION TWO: PROJECT ORGANIZATION AND RESPONSIBILITY

2.1 MANAGEMENT RESPONSIBILITIES

- # Lac Courte Oreilles Conservation Department, 13394 W. Trepania Rd., Hayward, WI 54843 (715) 865-2329
- # Project Managers- Lac Courte Oreilles Conservation Department, Environmental Engineer, Dan Tyrolt & Environmental Specialist, Brett McConnell
- # Field Technicians- Lac Courte Oreilles Conservation Department, Water Resource Technicians, Brett McConnell and Bill Nebel

The Project Managers are responsible for project planning, data validation, report preparation and project budget management. The Field Technicians are responsible for the preparation of the QAPP, following all SOPs and other monitoring plan requirements.

- # USEPA Region V, AE-17 J, 77 W. Jackson Blvd, Chicago IL 60604-3590
- # Project Officer- Irene Cook Phone: (312) 886-1823
- # Technical Contact- Christine Urban Phone: (312) 886-3493

2.1.1 Field Responsibilities

The Project Manager and Field Technicians are responsible for insuring that all monitoring procedures are done correctly and consistently.

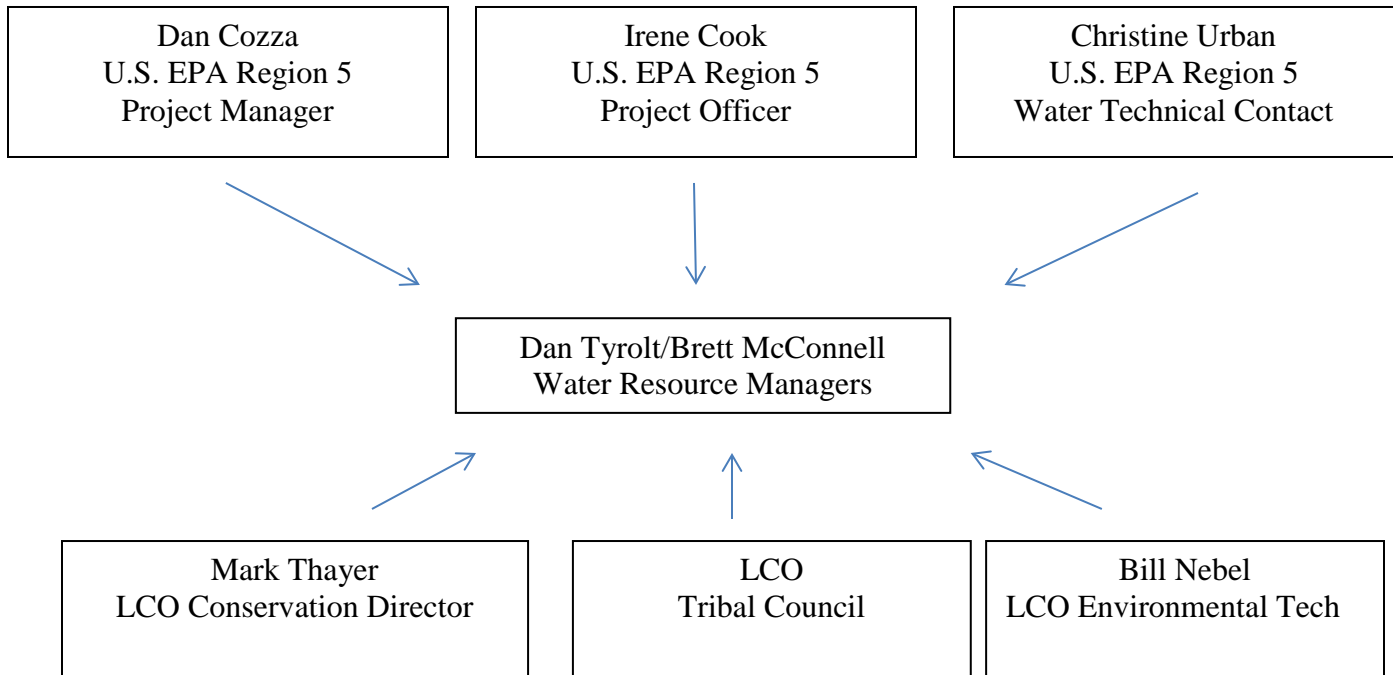
2.1.2 Laboratory Responsibilities

Northern Lake Service, Inc. is the contract laboratory for all water sample analysis. All lab SOPs for analysis of LCO=s water quality samples are contained in this document.

2.1.3 Corrective Action

The Project Manager or the technicians will be responsible for initiating, developing, approving and implementing the corrective actions. The EPA technical contact will be responsible for providing technical advice and consultation regarding the corrective actions.

2.1.4 Project Organization Diagram



2.2 QUALITY ASSURANCE RESPONSIBILITIES

The Project Manager and the Field Technicians will be responsible for following standard operating procedures and proper documentation of data in the field. Employees of the LCO Conservation Department have the following quality assurance responsibilities:

Project Manager:

- # Validates data-entry errors before data sheets are filed away
- # Conducts internal audits of calibration procedures and field activities
- # Provides proper corrective action documentation and procedures
- # Determines locations for Reservation DO monitoring
- # Oversees project budget

Environmental Technicians:

- # Conducts proper calibration and maintenance procedures for water quality meter
- # Prepares draft QAPP for project to be submitted to EPA for review and approval
- # Maintains field logbook documenting all information related to monitoring activities
- # Documents and reports data collection process problems to the Project Manager

SECTION THREE: QUALITY ASSURANCE OBJECTIVES FOR MEASUREMENT DATA

3.1 DISCUSSION OF QUANTITATIVE QA OBJECTIVES

3.1.1 Precision

Precision is a measure of the degree to which two or more measurements are in agreement. Precision of data collected for this project will be determined by taking two separate readings at the same location once for each day of monitoring. The relative percent difference (RPD) will be calculated for each pair of readings as indicated below:

$$RPD = \frac{(S-D) \times 100}{(S+D)/2}$$

where:

S= first reading

D=second reading

Field Precision will be reported as the RPD between the two co-located readings for each depth interval.

3.1.2 Completeness

Completeness is a measure of the amount of valid data obtained from a measurement system compared to the amount that was expected to be obtained for that measurement. Data completeness will be assessed for compliance with the amount of data required for decision making. The percent completeness is calculated as indicated below:

$$\% \text{Completeness} = \frac{(\text{number of valid measurements}) \times 100}{\text{number of measurements planned}}$$

where Avalid measurements@ refers to numbers of investigational samples obtained for a specific purpose, or in order to satisfy a particular project objective.

3.1.3 Representativeness

Representativeness expresses the degree to which data accurately and precisely represent a characteristic of a population, parameter variations at a sampling point, a process condition, or an environmental condition. Representativeness is dependent upon the proper design of the sampling program and will be satisfied by ensuring that the field sampling plan is followed and that proper sampling techniques are used.

3.1.4 Comparability

Comparability is an expression of the confidence with which one data set can be compared with another data set. Field data will be comparable by following all QA/QC objectives documented in this QAPP.

3.1.5 Accuracy

Accuracy will be accomplished by following all calibration procedures for the Hydrolab instruments. Standard operating procedures for calibration of these water quality meters can be found in the Appendix.

SECTION FOUR: SAMPLING PROCEDURES

4.1 SAMPLING ACTIVITY SUMMARY

The monitoring activities used in this work plan will be consistent with project objectives. Lakes, rivers and streams to be monitored can be found in Tables 1 & 2. Water quality parameters will be analyzed by the Project Manager.

4.2 SAMPLING EQUIPMENT AND PROCEDURES

4.2.1 Hydrolab Datasonde 4 Water Quality Meter

A multi-parameter water quality meter will be used by the LCO Conservation Department to gather surface water quality data. Each site location will be profiled at the surface and at each subsequent meter until it is at near bottom; depth is recorded for each measurement. Parameters selected will be programmed into the data display unit to be shown simultaneously for each profiling location. Readings will be taken immediately following parameter stabilization.

Maintenance of the meter will occur once a month and calibration procedures will be done daily before monitoring activities begin.

Storage of the water quality meter will be done by placing 1 inch of tapwater in the calibration and/or storage vessel, and placing the sonde with all probes in place in the vessel. The storage vessel will be sealed to prevent evaporation. A minimal amount of water will be used for storage so that the air in the chamber remains at 100 percent humidity. Also, the water level will be kept low enough so that none of the sensors are actually immersed. All Hydrolab maintenance SOPs will be followed. Hydrolab SOPs can be found in the Appendix.

4.2.2 Benthic Macro-invertebrate Sampling

Samples are collected by various methods depending on habitat and experimental design. In the littoral zone, samples will be collected using two methods, a 500um D-net, and a 3 2 inch diameter acrylic corer, with the sample taken in the top 10 cm. A petite Ponar will be used in deeper areas. Generally, samples are washed through a 500um mesh net and placed in a sample container, and preserved. All macro-invertebrate samples will be preserved with a 10% formalin solution.

Each sample will contain an interior and exterior label. Sample labels identify: 1) project name, 2) site name or number, 3) sample number and number of containers (i.e. large samples that are placed in multiple containers, A-D), 4) gear type (Ponar, D-net, corer, etc.), 5) sieve size used to wash sample, and, 6) current date.

Labels may be coded or include limited information, but must be referenced with an

accompanying log sheet that provides the required information from number 1 through 6. Interior labels written in pencil lead are required. Outside labels may also contain a brief description or code, but must include at least a unique identifier for lab sorting, prioritized processing, and archiving purposes.

4.2.3 Benthic Sample Inventory

A list of samples, including all label information, is completed in field notebooks as samples are collected. A sample list accompanies all samples returning to the laboratory. Chain of custody forms are completed and verified with the field sample list as in-coming samples are inventoried by laboratory personnel. Chain of custody forms and a field sample list are duplicated, filed with field notes or data sheets, and one copy placed in the project log book.

4.3 Phytoplankton Sampling

Phytoplankton assemblage requires 4-10 samples during the growing season to obtain a seasonal average. Counting of 300-500 cells to order will be done in the laboratory. The phytoplankton sample is preserved in the field with Lugol's solution. The sample is taken at the surface (.5m). Samples are fixed with 5% Lugol's Iodine and stored at 4 degrees Celsius.

4.4 Zooplankton Sampling

Zooplankton are sampled with vertical tows, using a plankton net equipped with a 7:1 reducing cone and 118um mesh. A single, vertical tow from .5m above bottom to the surface is sufficient. The recommended approach is to sample 4 to 6 times during the growing season to obtain seasonal averages. Identification and counting of 100-200 organisms, and measurement of daphnia size will be done in the laboratory.

4.5 Total Suspended Solids (TSS)

When taking a TSS sample, a clean bottle must be used for sample collection. The sample must be taken from undisturbed water; when standing in the stream, reach upstream into the current to obtain the sample. Because sediment loads may be non-uniformly distributed in the water column, it may be wise to determine TSS from a composite of several samples.

4.6 Total Phosphorus and Total Nitrogen Sampling

Water samples are collected using an integrated sampler. The device is a PVC tube 6.6 feet (2 meters) long with an inside diameter of 1.24 inches (3.2 centimeters) fitted with a stopper plug on one end and a valve on the other. The device allows collection of water from the upper two meters of the water column (within the euphotic zone). If the euphotic zone is < 2.0m deep, the integrated sampler will be lowered only to the depth of the euphotic zone, and additional draws will be taken to collect the volume needed for the samples.

Prior to taking each sample, the rubber stopper is removed and the sampler is rinsed by submerging it three times in the lake. With the valve open and the stopper off, the sampler is slowly lowered into the water as vertically as possible until the upper end is just below the surface. Cap and slowly raise the sampler. Close the valve when the bottom is near the surface. Empty the sample into sample bottle.

Laboratory methods pertaining to Total Phosphorus and Total Nitrogen analysis can be found in the Appendix in the NRRI AQuality Assurance and Quality Control Program.

4.7 Diatom Analysis /Core Dating & Mercury Sediment Analysis

Diatom analysis is a useful tool in examining the past history of a water body. Diatoms are a type of algae that grow abundantly and are well-preserved in sediments. Diatom species have unique features that enable them to be readily identified. Certain taxa are usually found under nutrient-poor conditions, whereas others are more common at elevated nutrient concentrations. Since ranges of favorable environmental conditions are known for many species, diatoms are especially useful in sediment-core analysis (Hall and Smol, 1999).

Mercury sediment analysis will help the LCOCD determine which lakes have higher mercury levels which may lead to higher consumption of methyl-mercury that accumulates in predator fish species like walleye pike, muskellunge and northern pike. The following are the protocols associated with diatom and mercury sediment sampling.

Diatom and mercury sediment samples will be taken together using the following procedure used by the USEPA A Survey of the Nation's Lakes Field Operations Manual.

Collecting the Sediment Core from Natural Lake Using Modified KB Corer

7. Record the lake ID and the date on three sample labels. Mark one label for the top interval (TOP), one for the bottom interval (BOTTOM), and one smaller label (from a separate sheet) for the sediment sample (SED). Attach the labels to two small plastic containers (for diatoms) and one 20 mL plastic (PET) vial (for sediment). Record the bar code numbers on the collection form.
8. If the bottom has been disturbed during the initial depth determination or for any other reason, move at least 5 m to take the core. It is critical that the corer strikes undisturbed surface sediments.
9. Put on surgical gloves. They must be worn during sample collection because the sediments may contain contaminants.
10. Insert the core tube into the sampling housing apparatus and tighten the hose clamp straps to secure the tube.

11. Attach the messenger to the sampler line and slowly lower the corer through the water column until the bottom of the core tube is 0.5 m above the sediment surface. While maintaining a slight tension on the line, let the line slip through the hands and allow the corer to settle into the bottom sediments. Immediately after the corer drops into the sediments, maintain line tension to prevent the corer from tilting and disturbing the core sample. (the goal is to obtain a core 45 cm in length. If this core length is not obtained the first time, the operation might need to be repeated at a new site using a greater release height in order to improve penetration and attain a longer core.)
12. Trip the corer by releasing the messenger weight so that it slides down the line.
13. Slowly raise the corer back to the surface, until the core tube and rubber seal are just under the water.
14. While keeping the seal under water, slowly tilt the corer until you can reach under the surface and plug the bottom of the corer with a rubber stopper. To do this without disturbing the water-sediment interface, you cannot tilt the corer more than 45 degrees.
15. Keeping your hand under the stopper, raise the corer into the boat in a vertical position. Stand the corer in a large tub to prevent contaminating the boat with sediment material.

Process the Sediment Core

1. Detach the core tube from the corer. One person should hold the sampler in a vertical position while the second person dismantles the unit.
2. Measure the length of the core to the nearest 0.1 cm and record the interval on the Sample Collection Form and on the two sample labels.
3. Slowly extrude the sample. To do this, position the extruder under the stopper at the base of the coring tube. Supporting both the core tube and the extruder in a vertical position, slowly lower the coring tube until the sediment is approximately 1 cm below the top of the tube.
4. Remove the water above the sediment core by using a siphon tube with a bent plastic tip (or a small disposable pipette) so that the surface sediments are not disturbed.
5. Continue extruding the core slowly and gently until the top of the core is just below the top of the core tube.
6. Do not open the pre-washed Asampling kit@ bag until its time to collect the sediment sample, and make sure the contents of the kit do not come into contact with anything other than the sediment sample.
7. Use the pre-washed 5-mL plastic pipette tip to collect a 1 cm³ sample from the center of the core. Use the wide end of the pipette tip like a corer and insert it into the core sample to the top of the collar on the tube (1 cm deep). Place your finger over the other end of the pipette tip to remove the sediment sample.
8. Transfer the removed sediment into the pre-labeled and pre-washed PET vial. Do not rinse the sample into the vial. Place the sediment sample on dry ice immediately to quick

freeze the sample, and keep frozen until shipment. Pipette tips are not re-used, so they should be rinsed with lake water or DI water and disposed of properly.

If sampling a Reservoir, go to steps 12-13 below. If sampling a natural lake, continue with steps 10-13.

10. Before collecting the bottom section, remove the sectioning apparatus and rinse in lake water. This procedure prevents contamination of the bottom sediment layer with diatoms from the upper portion of the core. This step is critical as a small amount of sediment contains millions of diatoms which would destroy the population structure needed to compare environmental conditions depicted by top and bottom core samples.
11. Continue extruding the sample, discarding the central portion in the tube, until the bottom of the stopper is approximately 5 cm (3 inches) from the top of the coring tube. Affix the sectioning apparatus to the top of the tube. Extrude the sample until the bottom of the stopper reaches the lower black line at the top of the tube (approximately 3 cm from the top of the tube). Section the extruded sediment (2cm) and discard. Rinse the sectioning tube with lake water. Without removing the sectioning apparatus from the coring tube, slightly tilt the tube and wash the sectioning stage with a small amount of water from a squirt bottle. Make sure the rinse water runs off the stage and not into the coring tube with sediment. Lower the tube until the top of the sediment is at the 1-cm mark on the sectioning tube. Collect the 1-cm section of core material in the second plastic container labeled for the BOTTOM interval. Record this interval on the Sample Collection Form and on the sample label for the bottom core. Discard the remaining 2 cm.
12. Cover the labels on each container completely with clear tape. Place containers in a cooler with bags of ice.
13. Rinse the corer, collection apparatus, and sectioning apparatus thoroughly with lake water. Rinse the tap water at the next sampling site.

4.8 Cyanobacteria Microcystin-LR Sampling

A 1-Liter amber glass bottle will be used and should be labeled before entering water. Gloves and waders will be worn; wade slowly to sampling location while trying to avoid agitating bottom sediment. Sampling should occur in water that is knee-deep. If a scum layer is present, samples should be collected there. Open the sampling bottle and grasp it at the base with one hand and plunge the bottle mouth downward into the water. The sampling depth should be approximately 3 to 6 inches below the surface of the water. Position the mouth of the bottle into the current away from your hand. If the water body is static, an artificial current can be created by moving the bottle horizontally with the direction of the bottle pointing away from you. Tip the bottle slightly upward to allow air to exit and the bottle to fill. Fill the bottle to about 1/3 full to allow room for expansion upon freezing. Tightly close the cap of the bottle.

Upon returning to shore, place the sample in a cooler with ice. Store and transport (to the State Lab of Hygiene) the sample on ice. Ship all samples on ice, in a cooler, to the Wisconsin State Laboratory of Hygiene the same day as samples were collected. Pack the bottles in the cooler carefully to inhibit breakage. Place laboratory slips in a zip-loc plastic bag in the cooler with the sample bottles.

Sample location on each lake will be determined by LCOCD Staff. Collection areas are usually chosen due to their close proximity to point-source discharges, high recreational areas, and wind blown sites.

4.9 DECONTAMINATION PROCEDURES

No heavy contamination is expected for this project. However, the water quality meter used will be decontaminated after each sampling location in order to avoid cross contamination between sites. The sonde will be rinsed with surface water from each sampling location before testing, and swung side-to-side at each sampling location depth interval.

Contaminant-free sample containers will be used for all sampling activities.

4.9.1 Field Quality Control

Duplicate profiling readings will be taken at one sampling location for each day of monitoring. Precision will be calculated by the RPD of each depth interval from the two readings.

Sampling bottles with preservatives are provided by Northern Lake Service along with chain of custody forms.

Duplicate nutrient sampling will occur periodically throughout ice-out conditions, and during cranberry harvest discharge events. These analyses measure both sampling and laboratory precision; performing another method of quality control.

SECTION FIVE: CUSTODY PROCEDURES

5.1 FIELD CUSTODY PROCEDURES

A field logbook will be used by the technicians to document all information related to surface water monitoring activities. Logbook entries will include: time, date, location, site description, weather conditions and personnel present. All pages will be signed and dated.

For samples that need to be shipped to the contract laboratory, all necessary chain of custody (COC) procedures will be followed. These include: properly labeling each sample with time, date, site code, sampler name and analytical parameter.

COC forms will be filled out, signed and dated by LCOCD staff. Copies of COC forms will be made and filed at the LCOCD.

5.1.1 Benthic Sampling Custody Procedures

Each sample will contain an interior and exterior label. Sample labels identify: 1) project name, 2) site name or number, 3) sample number and number of containers (i.e. large samples that are placed in multiple containers, A-D), 4) gear type (Ponar, D-net, corer, etc.), 5) sieve size used to wash sample, and, 6) current date.

Labels may be coded or include limited information, but must be referenced with an accompanying log sheet that provides the required information from number 1 through 6. Interior labels written in pencil lead are required. Outside labels may also contain a brief description or code, but must include at least a unique identifier for lab sorting, prioritized processing, and archiving purposes.

5.2 LABORATORY CUSTODY PROCEDURES

5.2.1 Laboratory Sample Inventory

A list of samples, including all label information, is completed in field notebooks as samples are collected. A sample list accompanies all samples returning to the laboratory. Chain of custody forms are completed and verified with the field sample list as in-coming samples are inventoried by laboratory personnel. Chain of custody forms and a field sample list are duplicated, filed with field notes or data sheets, and one copy placed in the project log book.

5.3 FINAL EVIDENCE FILE

A final evidence file will be created for all evidence and project-related data relevant to sampling activities described in this QAPP. The file will include (but not limited to) field notebooks, photographs, progress reports, COC forms, QA reports and all project-related documentation. All files pertaining to this QAPP are backed up and secured by Norton and a backup file is also stored in hard copy and digital format at another location.

SECTION SIX: CALIBRATION PROCEDURE AND FREQUENCY

6.1 FIELD INSTRUMENT CALIBRATION

The field instruments to be used, the Hydrolab MS 5, and the Hydrolab Datasonde 4, will be calibrated prior to the beginning of each scheduled monitoring time. All Hydrolab standard operating procedures for calibration will be followed. Slight variations may occur with individual parameters. To maintain accurate results, calibration procedures will be done thoroughly and consistently before each monitoring period. Hydrolab SOPs can be found in the Appendix.

SECTION SEVEN: ANALYTICAL PROCEDURES

Surface water will be field analyzed for the following parameters: dissolved oxygen, specific conductivity, temperature, pH and total dissolved solids.

7.1 FIELD ANALYTICAL PROCEDURES

Field analysis will involve the use of the YSI and Hydrolab Multi-Parameter Water Quality Meters. Regular maintenance of the water quality meter is conducted on a monthly basis and calibrated each day before monitoring. The SOPs for the water meter can be found in the Appendix.

7.2 LABORATORY ANALYTICAL PROCEDURES

7.2.1 Benthic Sample Processing

All benthic sample processing and analysis is performed for the LCOCD by the Natural Resources Research Institute in Duluth, MN. Prior to processing, samples preserved in the field with 10% formalin are rinsed to remove the formalin preservative. This procedure is conducted under a ventilation hood. The rinsed sample is then re-preserved in 70% ETOH. Discarded preservative are stored in containers labeled with appropriate hazardous waste information and transferred to Hazardous Chemical Storage.

Samples ready for processing are signed out of the project log book by lab personnel. Samples may contain multiple containers, so all containers for that sample are concurrently processed. All sample information contained inside the sample container should be verified with outside labels and project log book information. Due to the amount of material contained in a sample, it may be necessary to sub-sample or Asplit@ various samples. Protocols require a standard effort for processing each sample. One aspect of that framework is defined by the amount of time spent 'picking' a sample. The Contract laboratory whole-picks all content > 4 mm, and for the remainder (< 4 mm > 250 um mesh) they use a device to homogenate, then physically split (sub-sample) a sample in half, then that half in half. Depending on the original volume of material, the lab will start randomly processing an 1/8, usually 1/4 of the total volume to see how long it takes. NRRI follows up by processing the remaining fractions so that the total processing time does not drastically fall short of, nor exceed 8 hours.

Sample materials are washed in the appropriate sieve and a final rinse is conducted in a wash pan. The remaining sample is rinsed into a sorting pan and any material remaining in the wash pan that

passes through the sieve is discarded. Large amounts of material passing through the sieve are deposited in a waste receptacle and not discarded in the lab sink. Depending on the sediment type, samples can be washed using an elutriation device, colloidal silica bath, or other flotation procedures. These devices are designed to separate light organic materials from heavier particles in a sample.

Once the sample has been thoroughly washed and sub-sampled accordingly, the sample is transferred to a tray, glass pan, or sorting dish. Sample material should be spread evenly throughout the pan. Large trays and glass pans should be sorted using a 2X magnification lens. A dissecting scope is used to process samples placed in a sorting dish. Organisms are removed from detritus with a forceps and placed in labeled vials. Vial labels contain identical information as sample labels, with the addition of the amount of sample processed (i.e. 1/4, 2, or whole), a vial number, the total number of vials for that particular sample (e.g. 1 of 3), and initials of lab personnel. The number of vials accompanying each sample will depend on the abundance of organisms, but one vial should be designated for only midge larvae. All samples will be subjected to QA/QC inspection.

7.2.2 Macro-Invertebrate Sample Identification

Sample vials containing processed macro-invertebrates are then signed out for identification using the vial chain of custody form. Organisms are identified to the lowest taxonomic level using appropriate keys, enumerated, and recorded on an identification data sheet. A reference collection is made for each individual taxa identified for the entire project. The collection is then subject to QA/QC guidelines that include re-identifying 30% of the collection. If more than 5% of the randomly selected taxa are questioned, the entire collection is re-identified. This is performed internally by lab personnel.

Individual Mounts

Individuals within the family Chironomidae (Diptera) are permanently mounted for further taxonomic identification. Generic identification requires head capsule decapitation to ensure ventral viewing of individual mouth parts. Organisms are soaked in 95% ETOH, preserved in euparal mounting medium, and placed under a cover slip. Generally, the number of individuals per slide depends upon body size. Individual placement on the slide and label information will follow standard template.

Individual Identification

Permanent slide mounts will be identified to the lowest taxonomic level under a compound microscope. Each individual will be assigned a particular slide number, position, and side, so a separate reference collection for these organisms is not necessary because location of individual organisms can be easily assigned. Chironomids will also be subjected to a 30% random re-identification for lab verification.

7.2.3 Macro-invertebrate Data Entry

Data from laboratory sheets will be entered in a Microsoft Access database, or entered in duplicate using a standard spreadsheet software. The data are subject to a 10% random evaluation according to the number of data records. An error rate greater than 1% will result in re-entry.

Data are merged with a database (bugspec.xls) in SAS to check for errors and provide higher taxonomic categories for all individuals identified. Individuals not listed in the database are either re-identified or the current information and taxonomic name are compared to the ITIS system database for confirmation.

7.2.4 Phytoplankton Sample Processing and Identification

Whole water samples are fixed with ~ 5% Lugol's Iodine and stored at 4 C. For counting, sample is mixed well and a 20-30 mL aliquot is poured into a 45 mL Utermohl chamber (made at NRRI) prefilled with ~ 20 mL tap water (see Sandgren and Robinson 1984). Samples are allowed to settle a minimum of 24 hrs.

Algal scans are made using an Olympus IM inverted microscope. The slide is scanned at 400x and cells are identified to genus and species if possible. Then % biomass is estimated at 200X based on cell size, growth form and density. Often, biomass estimates are difficult to make due in both high and low density samples. In some cases, several Genera within the same class are clumped together and given a group biomass estimate.

NRRI most commonly uses Prescott, 1982 to identify cells to genus/species. Willen et al and Anton and Duthie are used to identify Cryptomonads.

7.2.5 Zooplankton Sample Processing and Identification

Density estimates for each sample will be based on (1) quantitative sub-samples of 100 specimens from each of the taxonomic groups and (2) searches of at least half the sample for the rare taxonomic groups. Three major taxonomic groups, cladocerans, copepods, and rotifers, will be categorized and counted. Cladocerans are distinguished as *Daphnia*, *Bosmina*, *Diaphanosoma*, *Chydorus*, *Ceriodaphnia*, *Holopedium*, or *Leptodora kindti*.

Cladocerans are often referred to as water fleas and vary between 0.2 and 3mm in length. Cladocerans are common in northern temperate lakes especially in the summer, and all but *L. kindti* are primarily herbivorous.

Copepods, a second major group of zooplankton, are distinguished as either *Cyclopoid* copepods or *Calanoid* copepods for copepodid stages. Nauplii, immature copepods in the naupliar stage, are categorized as copepod nauplii.

Rotifers are the third major taxonomic group of zooplankton quantified. Rotifers are ubiquitous in freshwater and are a highly diverse taxonomic group in both size (40 μ m to 2.5mm) and feeding behaviors (herbivores, detritivores, and omnivores).

In addition to the three major taxonomic groups, *Chaoborus* and *Chironomids* will be quantified. These are aquatic stages of insects found in the plankton, which can be important predators of zooplankton. These invertebrate predators are known to migrate into the sediments during the day to avoid visual predation by fishes and therefore the data will be regarded as presence/absence information and not faithful density estimates.

Two density estimates will be provided for each sample, the number of each taxonomic group per square foot, and the number of each taxonomic group per cubic foot. The latter takes into account the depth of the sampling site and is a common method to compare abundances across sites with different depths. A total density of zooplankton for each sample will also be provided.

Four total summary indices will be calculated for each sample, the Shannon Diversity Index, the Gannon Index, and two cladoceran size indices.

The Shannon Diversity Index is used to determine the diversity of each sample. This index uses the number of taxonomic groups and their relative abundance to estimate how much biological diversity is present at the site.

The Gannon Index is used to compare the productivity or trophic status of the sites sampled. This ratio is defined as the ratio of *Calanoid* copepod density to the sum of *Cyclopoid* copepod density and cladoceran density. The Gannon Index is useful in comparing the trophic status of multiple locations or sampling times in a single lake, or among different lakes. If the Gannon index is a smaller number, the productivity of a lake is high, or tends toward the more eutrophic side of the spectrum.

A size index will be used to compare the density of small cladocerans (*Bosmina*, *Ceriodaphnia*, and *Chydorus*) to the total density of cladocerans. A high value for this size index might indicate that size selective predation (SSP) by fish is intense and planktivorous fish are abundant.

The ratio of *Daphnia* to *Bosmina* will also be calculated. This ratio, although helpful in assessing SSP, is primarily an indication of food quality for herbivorous plankton. A high *Daphnia* to *Bosmina* ratio might indicate the predominance of lower quality phytoplankton.

7.2.6 Total Phosphorus, Total Nitrogen, Chl. A, Total Suspended Solids Analytical

Procedures

Laboratory methods pertaining to Total Phosphorus, Total Nitrogen, Chl. A and Total Suspended Solids analysis can be found in the Appendix in the Northern Lake Service, Inc. AQuality Assurance and Quality Control Program@ Manual.

Parameter	Holding Times	Preservation	Sample Container	EPA Method	LOD
Total Phosphorus	28 Days	Sulfuric, Cool 6° C	Plastic 250 ML	365.2	.007 mg/L
Nitrogen, Total Kjeldahl	28 Days	Sulfuric, Cool 6° C	Plastic	351.2	.089 mg/L
Chlorophyll-a	28 Days	Freeze in Dark	Plastic Amber	10200-H	-
Total Suspended Solids	7 Days	NP, Cool 6° C	Plastic 125 ML	EPA 160.2	1.0 mg/L

7.2.8 Sediment Diatom Methods

Laboratory methods for sediment diatom analysis can be found in the Appendix.

7.2.9 Cyanobacteria Toxin Analysis

Analysis of the Cyanotoxin Microcystin by the Elisa Method can be found in the Appendix.

SECTION EIGHT: INTERNAL QUALITY CONTROL CHECKS

8.1 FIELD QUALITY CONTROL CHECKS

The QC procedure for dissolved oxygen, pH, specific conductance, total dissolved solids and temperature measurements of surface water involve the calibration of the water quality meter as described in the YSI and Hydrolab SOP=s.

8.2 LABORATORY QUALITY CONTROL CHECKS

The Wisconsin State Lab of Hygiene and the Natural Resources Research Institute follow strict QA/QC protocols outlined throughout this document.

SECTION NINE: DATA REDUCTION, VALIDATION AND REPORTING

9.1 DATA REDUCTION

9.1.1 Field Data Reduction

Field data reduction procedures will be minimal due to the equipment being used. The YSI and Hydrolab Multi- Parameter Water Quality Meters will generate measurements that are directly read from its data display component. Information taken from the data display will be transferred onto site-specific surface water quality profiling data sheets immediately upon taking a reading.

9.2 DATA VALIDATION

The primary procedures that will be used to evaluate field data include checking for transcription errors and review of data sheets and data entry. It is the Project Manager=s responsibility to validate data-entry errors before data sheets are filed away.

9.3 DATA REPORTING

Measurements taken from the field will be reported on data sheets; calibration activities performed in the field will be documented in a field logbook. The Project Manager will be responsible for field data recording, data entering and preparation of final reports. Data received from the contract laboratories will be downloaded into the LCO Water Quality database in Quattro Pro and Excel Spreadsheet format.

SECTION TEN: PERFORMANCE AND SYSTEM AUDITS

10.1 FIELD PERFORMANCE AND SYSTEM AUDITS

Internal audits of calibration procedures and field activities will be performed by the Project Manager. The Project Manager will examine, verify, or correct all information monthly to ensure project consistency.

SECTION ELEVEN: PREVENTATIVE MAINTENANCE

11.1 FIELD INSTRUMENT PREVENTATIVE MAINTENANCE

Proper calibration and maintenance procedures for the water quality meter will be followed to prevent, or reduce down time. The main preventative maintenance concern is proper short-term storage of the sonde. The key for interim storage is to use a minimal amount of water so that the air in the chamber remains at 100 percent humidity, but the water level is low enough so that none of the sensors are actually immersed. Other preventative maintenance is to make sure the storage vessel is sealed, the data display unit is recharged daily, and the vessel is checked periodically to make certain that water is still present.

SECTION TWELVE: DATA QUALITY ASSESSMENT

It is the Project Manager's responsibility to perform data quality assessment. The quality of the data will be determined by its usability in decisions made regarding water quality management on the LCO Reservation.

Reference sites will be selected to compare and assess the monitoring data acquired in the study. Similar water bodies that are not currently developed or exposed to contamination sources will be chosen for comparison.

SECTION THIRTEEN: CORRECTIVE ACTION

13.1 FIELD CORRECTIVE ACTION

Corrective action may be required for field equipment problems. Re-calibration procedures and part replacement will all be documented in the field logbook. All corrective actions taken during the project will be maintained in the project file. The Project Manager is responsible for proper corrective action documentation and procedures.

SECTION FOURTEEN: QUALITY ASSURANCE REPORTS TO MANAGEMENT

A quality assurance report will be produced at the end of the project period. This report will contain: data validation and assessment results, field audit results, QA/QC problems and corrective actions taken during the project. Monthly reports will also be submitted to the LCO Project Manager to ensure that problems arising during the monitoring phase are investigated and corrected.

Tables

Table 1 Surface Water Monitoring Locations-Lakes

Table 2 Surface Water Monitoring Locations-Rivers, Streams and Creeks

Figures

Figure 1 Location of the Lac Courte Oreilles Reservation

Figure 2 USGS Gaging Stations in the Chippewa River Basin

Figure 3 Project Task Bar Chart and Associated Time frames

Figure 4 LCO Water Quality Project Organization Diagram

Appendix

Appendix 1 LCOCD SOPs for YSI Water Meter and Calibration Procedures



Catalog Number 003078HY

Hydrolab DS5X, DS5, and MS5 Water Quality Multiprobes

USER MANUAL

February 2006, Edition 3

Table of Contents

Section 1 Specifications	5
Section 2 General Information	9
2.1 Safety Information	9
2.1.1 Use of Hazard Information	9
2.1.2 Precautionary Labels	9
2.2 DS5, DS5X Multiprobe	10
2.3 MS5 Multiprobe	10
2.4 Sensor Options	11
2.4.1 DS5 Sensor Options	12
Section 3 Installation	15
3.1 Unpacking the Instrument	15
3.2 Instrument Assembly	15
3.3 Power Options	16
Section 4 Operation	19
4.1 Parameter Setup	19
4.1.1 Using the Surveyor for Parameter Setup	19
4.1.2 Using Hydras 3 LT for Parameter Setup	20
4.1.3 Specific Conductance Parameter Setup	20
4.1.4 Clark Cell Dissolved Oxygen Parameter Setup	22
4.1.5 pH Parameter Setup	22
4.1.6 Other Parameter Setup	22
4.2 Calibration	22
4.2.1 Calibrating the Sensors Using the Surveyor	22
4.2.2 Calibrating the Sensors Using Hydras 3 LT	23
4.2.3 Calibration Preparation	24
4.2.4 Temperature Sensor Calibration	25
4.2.5 Specific Conductance Calibration	25
4.2.6 Clark Cell Dissolved Oxygen Sensor Calibration	25
4.2.6.1 Water-Saturated Air Dissolved Oxygen Calibration	25
4.2.6.2 Known Concentration Dissolved Oxygen Calibration	26
4.2.7 Pressure Sensor Calibration	27
4.2.8 pH/ORP Calibration	27
4.2.9 Other Sensor Calibrations	27
4.3 Using the DS5/MS5 for Short Term Deployments	27
4.3.1 Gathering Data Using the Surveyor	27
4.3.2 Gathering Data Using a PC and Hydras 3 LT	27
4.3.3 Using the DS5/DS5X/MS5 for Unattended Monitoring	27
4.3.3.1 Creating Log Files	27
4.3.3.2 Downloading Log Files	28
Section 5 Deployment	29
5.1 Deployment Considerations	29
5.1.1 Pressure Extremes	29
5.1.2 Temperature Extremes	29
5.1.3 Data Transmission Lines	29
5.1.4 Minimum Depth Requirements	29
5.2 Deployment in Open Waters	30
5.2.1 Minimum Clearance Requirements	30
5.2.2 Long-term Deployment in Open Waters	30
5.2.2.1 Anchoring the DS5 or DS5X using the Support Bail	31
5.2.2.2 Anchoring the MS5 using the Bail Kit	32
5.2.2.3 Anchoring the MS5 using the Mooring Fixture	32

Table of Contents

5.2.3 Short-term Deployment in Open Waters	33
5.2.4 Minimum Flow Requirements.....	35
5.2.5 Non-submersible Deployment.....	35
Section 6 Maintenance	37
6.1 Multiprobe and Accessory Maintenance.....	37
6.1.1 Cleaning the Multiprobe Housing	37
6.1.2 Dryer Maintenance.....	37
6.1.3 FreshFlow™ Miniature Sample Circulator Maintenance.....	38
6.2 Battery Replacement.....	38
6.2.1 DS5 and DS5X Battery Replacement	38
6.2.2 MS5 Battery Replacement	39
6.2.3 Lithium Battery Replacement	40
6.3 Storage and Care Recommendations	42
6.3.1 Multiprobe and Sensor Storage	42
6.3.2 Electrical Cable Care	42
6.4 Sensor Maintenance.....	43
6.5 Clark Cell Dissolved Oxygen Maintenance	43
6.6 Specific Conductance, Salinity, and TDS Maintenance	44
6.7 ORP Sensor Maintenance.....	44
6.8 pH Electrode Maintenance	44
6.8.1 Standard Reference Electrode	45
6.8.2 pH Integrated Sensor	46
6.9 Temperature Sensor Maintenance	46
6.10 Pressure Sensor Maintenance	46
6.11 Other Sensor Maintenance	46
Section 7 Replacement Parts and Accessories	47
Section 8 How to Order	49
Section 9 Repair Service	50
Section 10 Limited Warranty	51
Appendix A Troubleshooting	53
Appendix B External Communications	57
B.1 SDI-12 Interface	57
B.2 Connection to an External Device	58
B.3 RS485 Interface.....	60
B.4 Modbus Interface.....	60
B.5 Using a Modem with Multiprobes	62
B.6 TTY Mode.....	64
B.6.1 TTY Menu and Commands	65
B.6.2 Data Display	66
Appendix C Using HyperTerminal	67
C.1 HyperTerminal Setup	67
Appendix D Glossary & Abbreviations	69

Section 1 Specifications

Specifications are subject to change without notice.

DS5 and DS5X Transmitter	
Outer Diameter	8.9 cm (3.5 in.)
Length	58.4 cm (23 in.)
Weight (typical configuration)	3.35 kg (7.4 lb)
Maximum Depth	225 m
Operating Temperature	–5 to 50 °C
Battery Supply (optional)	8 C batteries
Computer Interface	RS232, SDI-12, RS485
Memory (optional)	120,000 measurements
MS5 Transmitter	
Outer Diameter	4.4 cm (1.75 in.)
Length	53.3 cm (21 in.) 74.9 cm (29.5 in.) with battery pack
Weight (typical configuration)	1.0 kg (2.2 lb) 1.3 kg (2.9 lb) with battery pack
Maximum Depth	225 m
Operating Temperature	–5 to 50 °C
Battery Supply (optional)	8 AA batteries
Computer Interface	RS232, SDI-12, RS485
Memory (optional)	120,000 measurements
Temperature Sensor	
Range	–5 to 50 °C
Accuracy	± 0.10 °C
Resolution	0.01 °C
Specific Conductance Sensor	
Range	0 to 100 mS/cm
Accuracy	± 1% of reading; ± 0.001 mS/cm
Resolution	0.0001 units
pH Sensor	
Range	0 to 14 units
Accuracy	± 0.2 units
Resolution	0.01 units

Specifications

Clark Cell Dissolved Oxygen Sensor	
Range	0 to 50 mg/L
Accuracy	± 0.2 mg/L at ≤ 20 mg/L ± 0.6 mg/L at > 20 mg/L
Resolution	0.01 mg/L
ORP	
Range	–999 to 999 mV
Accuracy	± 20 mV
Resolution	1 mV
Depth Vented Level	
Range	0 to 10 m
Accuracy	± 0.01 m
Resolution	0.001 m
Depth 0–25 m	
Range	0 to 25 m
Accuracy	± 0.05 m
Resolution	0.01 m
Depth 0–100 m	
Range	0 to 100 m
Accuracy	± 0.05 m
Resolution	0.01 m
Depth 0–200 m	
Range	0 to 200 m
Accuracy	± 0.1 m
Resolution	0.1 m
Hach LDO® Sensor	
Range	0–30 mg/L
Accuracy	± 0.01 mg/L for 0–8 mg/L; ± 0.02 mg/L for greater than 8 mg/L
Resolution	0.01 or 0.1 mg/L
Salinity	
Range	0 to 70 ppt
Accuracy	± 0.2 ppt
Resolution	1 mV
4-beam Turbidity (DS5 Only)	
Range	0 to 1000 NTU
Accuracy	± 5% of reading; ± 1 NTU
Resolution	0.1 NTU (<100 NTU); 1NTU (≥ 100 NTU)

Self-cleaning Turbidity	
Range	0 to 3000 NTU
Accuracy	$\pm 1\%$ up to 100 NTU, $\pm 3\%$ up to 100–400 NTU, $\pm 5\%$ from 400–3000 NTU
Resolution	0.1, up to 400 NTU; 1.0, 400–3000 NTU
Ammonium/Ammonia	
Range	0 to 100 mg/L-N
Accuracy	Greater of $\pm 5\%$ of reading or ± 2 mg/L-N (typical)
Resolution	0.01 mg/L-N
Nitrate	
Range	0 to 100 mg/L-N
Accuracy	Greater of $\pm 5\%$ of reading or ± 2 mg/L-N (typical)
Resolution	0.01 mg/L-N
Chloride	
Range	0.5 to 18,000 mg/L
Accuracy	Greater of $\pm 5\%$ of reading or ± 2 mg/L (typical)
Resolution	0.0001 units
Total Dissolved Gas	
Range	400 to 1300 mmHg
Accuracy	$\pm 0.1\%$ of span
Resolution	1.0 mmHg
Ambient Light	
Range	0 to 10,000 $\mu\text{mol s}^{-1} \text{m}^{-2}$
Accuracy	$\pm 5\%$ of reading or ± 1 $\mu\text{mol s}^{-1} \text{m}^{-2}$
Resolution	1 $\mu\text{mol s}^{-1} \text{m}^{-2}$
Chlorophyll a	
Range	0 to 500 $\mu\text{g/L}$, 0 to 50 $\mu\text{g/L}$, 0 to 5 $\mu\text{g/L}$
Accuracy	$\pm 3\%$ for signal level equivalents of 1 ppb Rhodamine WT dye
Resolution	0.01 $\mu\text{g/L}$
Rhodamine WT	
Range	0 to 1000 ppb, 0 to 100 ppb, 0 to 10 ppb
Accuracy	$\pm 3\%$ for signal level equivalents of 1 ppb Rhodamine WT dye
Resolution	0.01 ppb
Blue-green Algae	
Range	100 to 2,000,000 cells/mL, 100 to 200,000 cells/mL, 100 to 20,000 cells/mL
Accuracy	$\pm 3\%$ for signal level equivalents of 1 ppb Rhodamine WT dye
Resolution	0.01 cells/mL

Section 2 General Information

2.1 Safety Information

Please read this entire manual before unpacking, setting up, or operating this instrument.

Pay particular attention to all danger and caution statements. Failure to do so could result in serious injury to the operator or damage to the equipment.

Do not use or install this equipment in any manner other than that which is specified in this manual.

2.1.1 Use of Hazard Information

If multiple hazards exist, this manual will use the signal word (Danger, Caution, Note) corresponding to the greatest hazard.

DANGER

Indicates a potentially or imminently hazardous situation which, if not avoided, could result in death or serious injury.

CAUTION









Indicates a potentially hazardous situation that may result in minor or moderate injury.

Important Note: Information that requires special emphasis.

Note: Information that supplements main points in the text.

2.1.2 Precautionary Labels

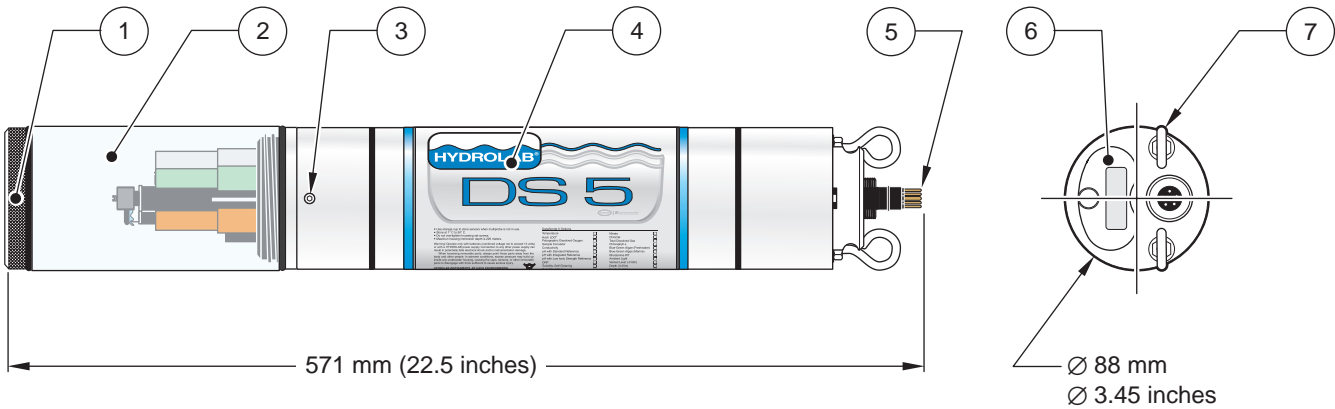
Read all labels and tags attached to the instrument. Personal injury or damage to the instrument could occur if not observed.

	This symbol, when noted on the instrument, references the instruction manual for operation and/or safety information.
	This symbol, when noted on a product enclosure or barrier, indicates that a risk of electrical shock and/or electrocution exists and indicates that only individuals qualified to work with hazardous voltages should open the enclosure or remove the barrier.
	This symbol, when noted on the product, identifies the location of a fuse or current limiting device.
	This symbol, when noted on the product, indicates that the marked item can be hot and should not be touched without care.
	This symbol, when noted on the product, indicates the presence of devices sensitive to Electro-static Discharge and indicates that care must be taken to prevent damage to them.
	This symbol, when noted on the product, identifies a risk of chemical harm and indicates that only individuals qualified and trained to work with chemicals should handle chemicals or perform maintenance on chemical delivery systems associated with the equipment.
	This symbol, when noted on the product, indicates the need for protective eye wear.
	This symbol, when noted on the product, identifies the location of the connection for Protective Earth (ground).

2.2 DS5, DS5X Multiprobe

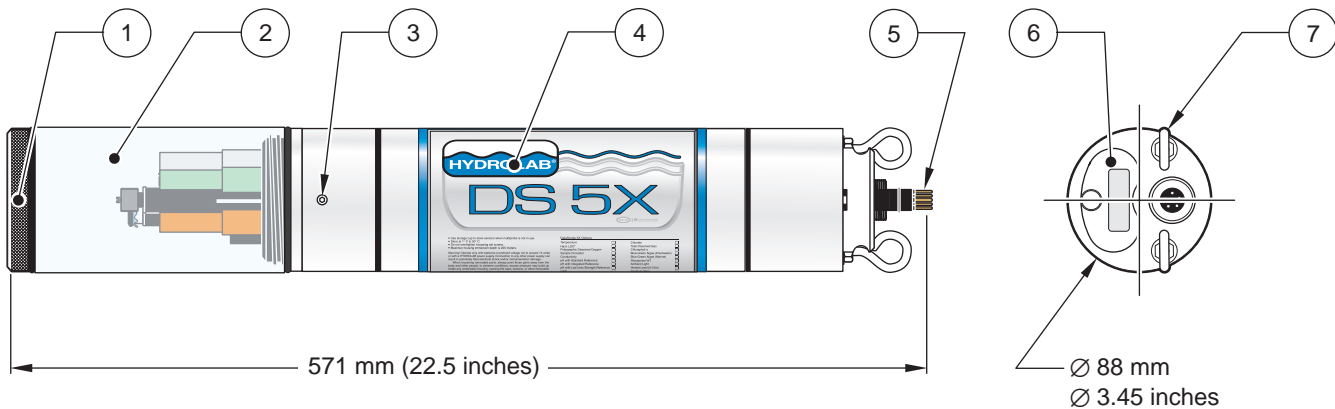
The DS5 and DS5X are designed for in-situ and flow-through applications, and can measure up to 15 parameters simultaneously. The DS5 and DS5X have seven configurable ports that can include up to ten of the following sensors: ambient light, ammonia, chloride, chlorophyll a, rhodamine WT, conductivity, depth, dissolved oxygen, nitrate, ORP, pH, temperature, total dissolved gas, turbidity, and blue-green algae.

Figure 1 DS5 Multiprobe



1. Calibration Cup	5. Bulkhead Connector
2. Storage Cup	6. Battery Compartment (optional)
3. Locking Screw	7. Bail Attachment
4. Housing	

Figure 2 DS5X Multiprobe



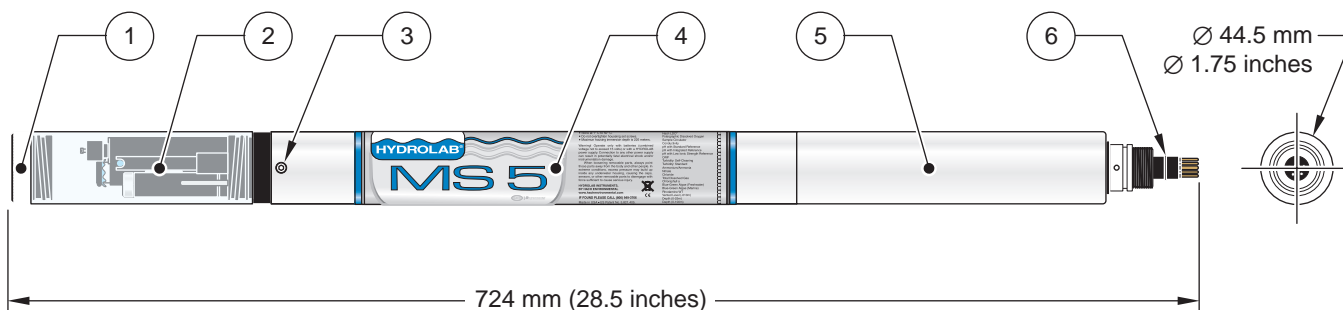
1. Calibration Cup	5. Bulkhead Connector
2. Storage Cup	6. Battery Compartment (optional)
3. Locking Screw	7. Bail Attachment
4. Housing	

2.3 MS5 Multiprobe

The MS5 is a portable instrument used for long-term monitoring or profiling applications. The MS5 has four configurable ports that can include a combination of the following sensors: ammonia, chloride, chlorophyll a, rhodamine WT, conductivity, depth, dissolved

oxygen, nitrate, ORP, pH, temperature, total dissolved gas, turbidity, and blue-green algae.

Figure 3 MS5 Multiprobe





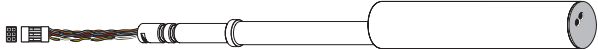
1. Calibration Cap	4. Housing
2. Calibration Cup	5. Battery Compartment (optional)
3. Locking Screw	6. Connector

2.4 Sensor Options



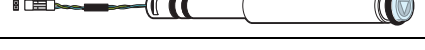
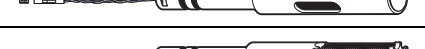
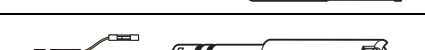










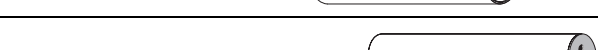
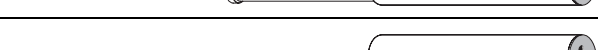
MS5 Sensor Options

Sensor	Description	Cat. No.
	Hach LDO® Sensor	007455
	Clark Cell Dissolved Oxygen/Conductivity	004467
	Clark Cell Dissolved Oxygen	004470
	Conductivity with pH Return	004468
	Total Dissolved Gas	004469
	pH and ORP, with Integrated Reference	004454
	pH with Integrated Reference	004446
	Low Ionic Strength Reference	004445
	pH	004461
	pH and ORP	004462
	Chloride	004496
	Nitrate	004494
	Ammonium/Ammonia	004492
	Standard Reference	004463
	Circulator	007245
	Self-cleaning Turbidity	007280
	Standard Turbidity	004466

MS5 Sensor Options

Sensor	Description	Cat. No.
	Chlorophyll a	007284
	Rhodamine WT	007285
	Blue-green Algae	007293

2.4.1 DS5 Sensor Options

Sensor	Description	Cat. No.
	Hach LDO® Sensor	007455
	Clark Cell Dissolved Oxygen/Conductivity	004467
	Clark Cell Dissolved Oxygen	004470
	Conductivity with pH Return	004468
	Total Dissolved Gas	004469
	pH and ORP, with Integrated Reference	004454
	pH with Integrated Reference	004446
	Low Ionic Strength Reference	004445
	pH	004461
	pH and ORP	004462
	Chloride	004496
	Nitrate	004494
	Ammonium/Ammonia	004492
	Standard Reference	004463
	Circulator	007245
	4-beam Turbidity (DS5 only)	004524
	Standard Turbidity (DS5 only)	004466
	Self-cleaning Turbidity	007140
	Chlorophyll a	007202
	Rhodamine WT	007204

2.4.1 DS5 Sensor Options (continued)

Sensor	Description	Cat. No.
	Blue-green Algae	007291

DANGER

Only qualified personnel should conduct the tasks described in this section of the manual.

3.1 Unpacking the Instrument

Remove the multiprobe from its shipping carton and inspect it for any visible damage. Contact Customer Service at 1-800-949-3766 if any items are missing or damaged.

Note: It is normal for a small amount of solution to be in the cup.

3.2 Instrument Assembly

There are many ways to connect a multiprobe to a display or a personal computer.

DANGER

An electrical shock hazard can exist in a wet or outdoor environment, if the multiprobe is powered via the external 115 VAC power supply. The safest and preferred method of powering this equipment in wet or outdoor environments is with battery or solar power (with a combined voltage not to exceed 15 volts). If it is necessary to power the multiprobe with the 115 VAC power supply in a wet or outdoor environment, a Ground Fault Interrupt (GFI) circuit is required. The installation of the GFI device must be done by a licensed electrician.

1. Remove all protective plugs and keep them in a safe place, they will be used again for moving and storage.
2. Connect the calibration cable (Cat. No. 013470), or detachable cable (015XXX) to the multiprobe. The connectors are keyed for proper assembly. Align the bigger pin on the multiprobe male connector to the indicator dots on the female cable connector. Do not rotate the cable or force or twist the pins into the connectors to prevent damage to the connector pins.
3. Power the instrument by connecting the power receptacle from the calibration cable and external power adapter to an approved battery or power supply (see [Figure 4 on page 16](#)).
4. Connect the other end of the calibration cable, detachable cable, fixed cable, or external power adapter to the computer serial port.
5. Start the communications program (Hydras 3 LT).
6. The software will automatically scan for Sondes. All detected Sondes are displayed in the 'Connected Sondes' list in the Main window displayed below. If a Sonde is not found, reattach the data cable and press **RE-SCAN FOR SONDES**. Retry until the Sonde(s) are found.

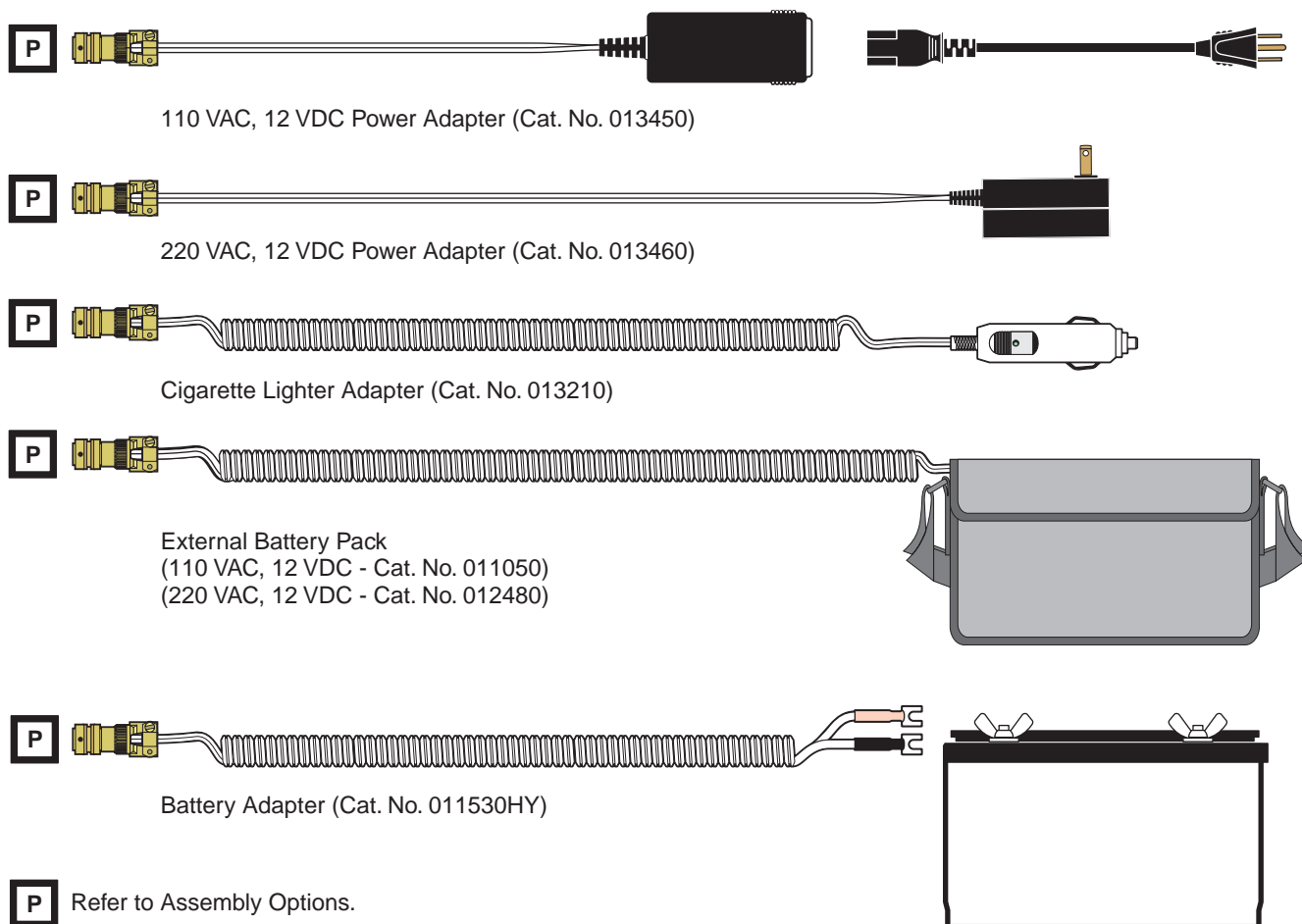
3.3 Power Options

A logging multiprobe can be powered by several sources:

- The DS5 and DS5X have an optional internal battery pack (IBP) holding 8 size C alkaline batteries.
- The MS5 has an optional internal battery pack holding 8 size AA alkaline batteries.
- Both multiprobes can use the external battery pack (EBP).
- Both multiprobes can use either of the following power supplies: the 110 VAC 12 VDC power adapter or the 220 VAC 12 VDC power adapter.
- Both multiprobes can use a customer-supplied 12-volt deep cycle battery with appropriate amp-hour capacity connected via the battery adapter or a cable with a 4-pin female metal shell connector.
- Both multiprobes can be powered using a Surveyor Datalogging Display, which is equipped as a standard with a 7.2V, 3.5 Ah NiMH rechargeable battery.

Note: Multiprobes configured with the Self-cleaning Turbidity and one or more fluorescence sensors (Chlorophyll a, Rhodamine WT, Blue-green Algae) require either an internal battery pack or an external power source other than the Surveyor.

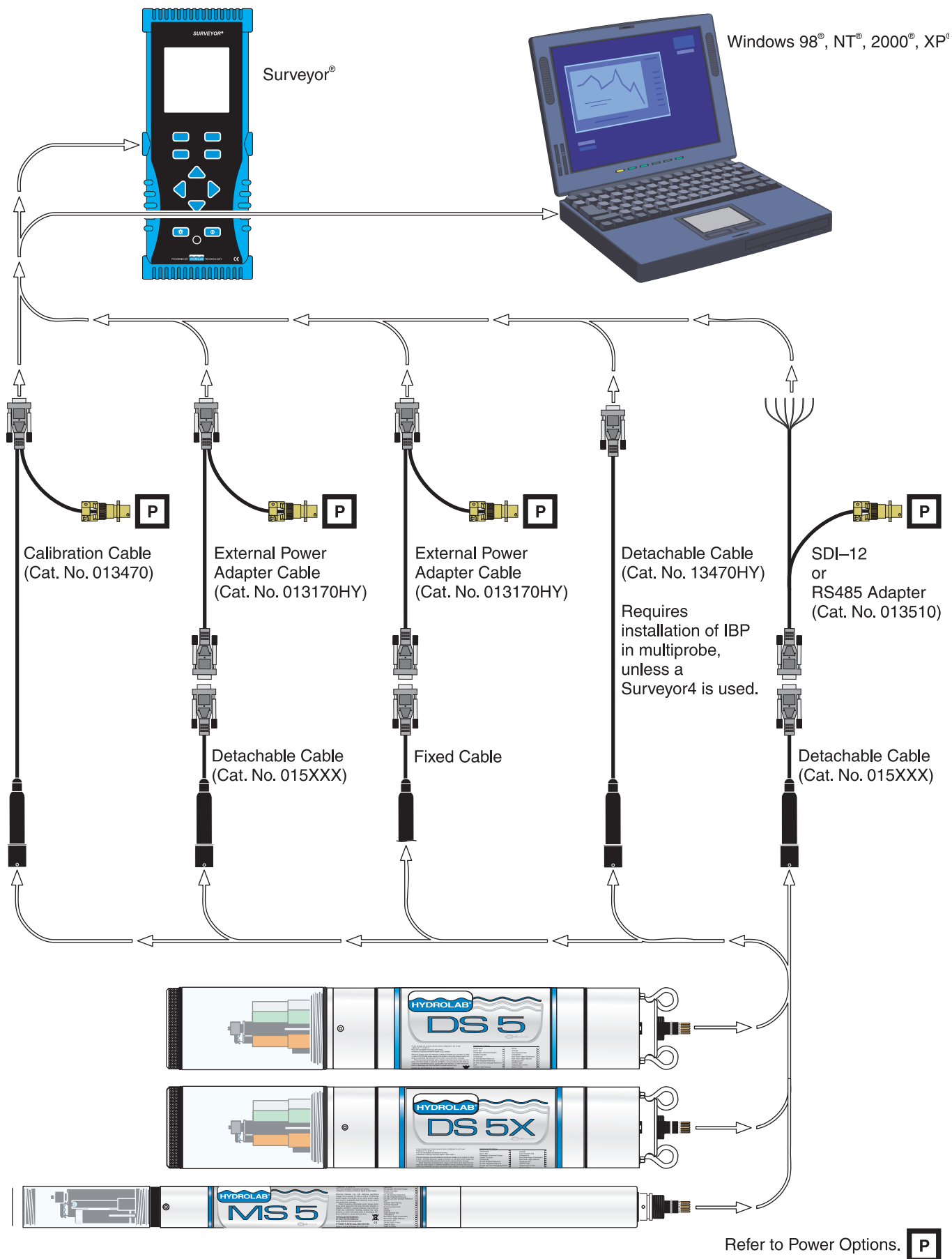
Figure 4 Power Options



*Use the correct power cord with the IEC 320 connector.

**To prevent damage, use a regulated 12 VDC adapter. An unregulated 12 VDC adapter may exceed the instrument voltage limit rating.

Figure 5 Assembly Options



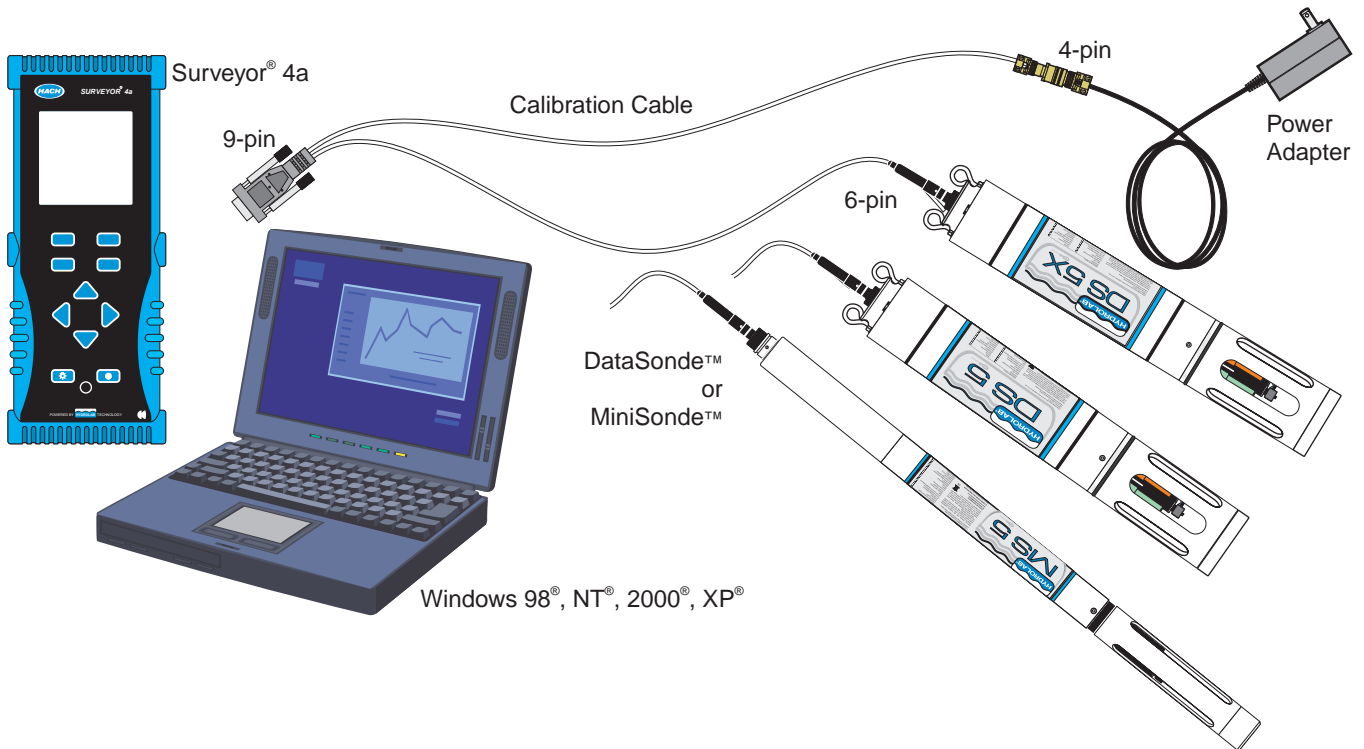
Section 4 Operation

CAUTION

When loosening removable parts from a multiprobe, always point those parts away from your body and other people. In extreme conditions, excess pressure may build-up inside any underwater housing, causing the caps, sensors, or other removable parts to disengage with force which may cause serious injury.

The Sondes use Hydras 3 LT or a Surveyor to set up parameters and calibrate the sensors.

Figure 6 **Operations Setup**



4.1 Parameter Setup

4.1.1 Using the Surveyor for Parameter Setup

For more information on the Surveyor, refer to the User Manual (Cat. No. 00719618).

1. Attach the power and data cable to the Sonde. Attach the 9-pin connector to the Surveyor.
2. Turn on the Surveyor. Wait approximately 10 seconds for initialization.
3. Press **SETUP/CAL**. Press **SETUP**. Press **SONDE**.
4. Highlight Parameters and press **SELECT**.
5. Use the **ARROW** keys to highlight the appropriate parameter and press **SELECT**.
6. Highlight the appropriate function and press **SELECT**. A configuration screen will be displayed. Depending on the application, use the **ARROW** keys to change the function, press **SELECT** and **DONE** to finish.

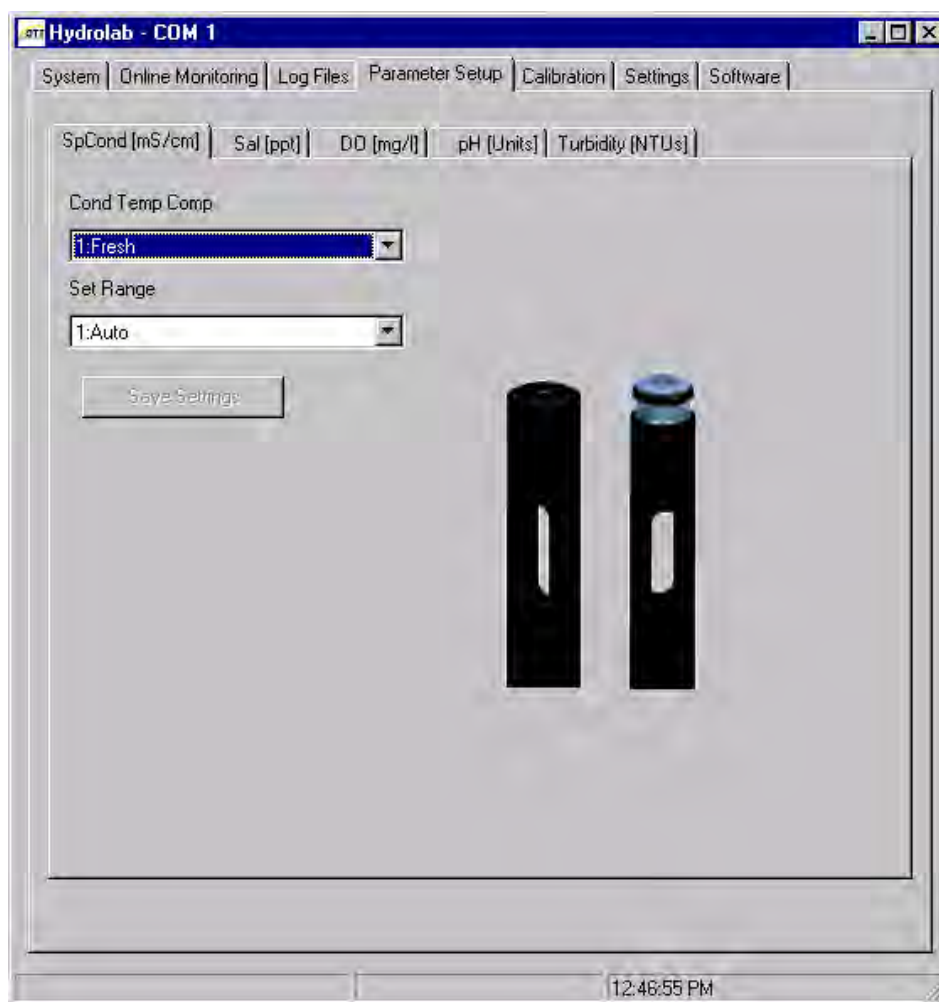
4.1.2 Using Hydras 3 LT for Parameter Setup

For more information on Hydras 3 LT, refer to the Quick Start Guide (Cat. No. 6234289) or press the **F1** key while Hydras 3 LT is active.

1. Attach the power and data cable to the Sonde. Attach the 9-pin connector to a PC.
2. Start Hydras 3 LT. Wait for the software to scan for connected Sondes. Highlight the multiprobe and press **OPERATE SONDE**.

Note: If the Sonde appears to be connected and the software does not recognize the Sonde connection, remove and replace the connector cable and press **RE-SCAN FOR SONDE**. Repeat until Hydras 3 LT recognizes the Sonde.

3. Click on the Parameter Setup tab and select the parameter tab to be configured.
4. Enter the appropriate values and press **SAVE SETTINGS**.



4.1.3 Specific Conductance Parameter Setup

For specific conductance set the following functions using Hydras 3 LT or the Surveyor:

- Select the specific conductance function (Fresh, Salt, StdMth, None, or Custom).
 - **Fresh** (default) is based on the manufacturer's freshwater temperature compensation. This function is derived from

$$0.01N\ KCl: f(T) = c_1T^5 + c_2T^4 + c_3T^3 + c_4T^2 + c_5T + c_6,$$

where:

$$c_1 = 1.4326 \times 10^{-9}, c_2 = -6.0716 \times 10^{-8}, c_3 = -1.0665 \times 10^{-5}, c_5 = -5.3091 \times 10^{-2}, c_6 = 1.8199.$$

- **Salt** is based on the manufacturer's saltwater compensation.

$$f(T) = c_1T^7 + c_2T^6 + c_3T^5 + c_4T^4 + c_5T^3 + c_6T^2 + c_7T + c_8$$

where:

$$c_1 = 1.2813 \times 10^{-11}, c_2 = -2.2129 \times 10^{-9}, c_3 = 1.4771 \times 10^{-7}, c_4 = -4.6475 \times 10^{-6}, \\ c_5 = 5.6170 \times 10^{-5}, c_6 = 8.7699 \times 10^{-4}, c_7 = -6.1736 \times 10^{-2}, c_8 = 1.9524.$$

- **StdMth** will remove any temperature compensation, so the readings are equivalent to conductivity: $f(T)=1$.
- **Custom** will provide a compensation function that the user can define according to the following function:

$$f(T) = aT^7 + bT^6 + cT^5 + dT^4 + eT^3 + fT^2 + gT + h.$$
- Select the Set Range (1:Auto, 2:High, 3:Mid, or 4:Low).
 - **Auto** (default) allows the multiprobe to automatically select the most appropriate range to measure conductivity. The multiprobe will dynamically change the range based on the current measurement conditions over 0–100 mS/cm. The resolution of the displayed data will also change to accommodate the current range in use.
 - **High, Mid, and Low** force the multiprobe to measure conductivity using a fixed range. If low range is selected, the readings will indicate an over-ranged condition for values above 1.5 mS/cm. The Mid range will over-range at 15 mS/cm. These choices also force the displayed readings to a fixed point or constant resolution format primarily only needed for certain SDI-12 data loggers. Otherwise, it is best to always select the Auto choice as this gives the best accuracy and performance for the conductivity sensor.
- Select the computation method for salinity (1:2311 or 2:StdMth).
 - **2311** (default): salinity is computed using an algorithm adapted from the United States Geological Survey Water-Supply Paper 2311 titled "Specific Conductance: Theoretical Considerations and Application to Analytical Quality Control". This salinity function is only defined from salinities in the 30 to 40 ppt range (mild concentrations and dilutions of sea water). This salinity function uses specific conductance values C in mS/cm compensated.

$$\text{Salinity} = c_1C^4 + c_2C^3 + c_3C^2 + c_4C + c_5$$

where:

$$c_1 = 5.9950 \times 10^{-8}, c_2 = -2.3120 \times 10^{-5}, c_3 = 3.4346 \times 10^{-3}, c_4 = 5.3532 \times 10^{-1}, \\ c_5 = -1.5494 \times 10^{-2}.$$

- **StdMth**: salinity will be computed using the Practical Salinity Scale (1978). This algorithm is defined for salinities ranging from 2 to 42 ppt and uses conductivity values corrected to 15 °C, regardless of the compensation function selected for specific conductance. This algorithm is described in section 2520B of "Standard Methods for the Examination of Water and Wastewater", 18th edition.

4.1.4 Clark Cell Dissolved Oxygen Parameter Setup

For dissolved oxygen, set the following functions using Hydras 3 LT or the Surveyor: Enable or Disable Salinity Compensation.

4.1.5 pH Parameter Setup

For pH, set the following functions using Hydras 3 LT or the Surveyor: Select either 2 or 3 calibration points.

4.1.6 Other Parameter Setup

Refer to the sensor specific instruction sheet for more information.

4.2 Calibration

Sensors are checked for calibration before they leave the factory, however calibration needs to be specific for a site and application. Check the calibration prior to the first use.

Calibrate the sensors when:

- Fouling has occurred or is noticeable (site-specific).
- Parameter measurements do not match those of a known calibrated standard.
- Adding or removing certain components for different applications (e.g., the circulator) or when replacing components (e.g., the Teflon junction of the pH reference electrode).

Some system components are affected by time, usage, and the environment. To ensure instrument accuracy, it is recommended to perform routine tests of the system under standard conditions. The multiprobe can be calibrated in the field or at a facility. Equipment checks and adjustment made before going to the field tend to be more precise than those made under field conditions.

4.2.1 Calibrating the Sensors Using the Surveyor

For more information on the Surveyor, refer to the User Manual (Cat. No. 00719618).

1. Attach the power and data cable to the Sonde. Attach the 9-pin connector to the Surveyor.
2. Turn on the Surveyor. Wait approximately 10 seconds for initialization.
3. Press **SETUP/CAL**. Press **CALIBRATION**. Press **SONDE**.
4. Use the **ARROW** keys to highlight the appropriate parameter and press **SELECT**.
5. Highlight the function to program and press **SELECT**. A calibration screen will be displayed. Depending on the application, use the **ARROW** keys to change the function, press **SELECT**, and **DONE** to finish the calibration.

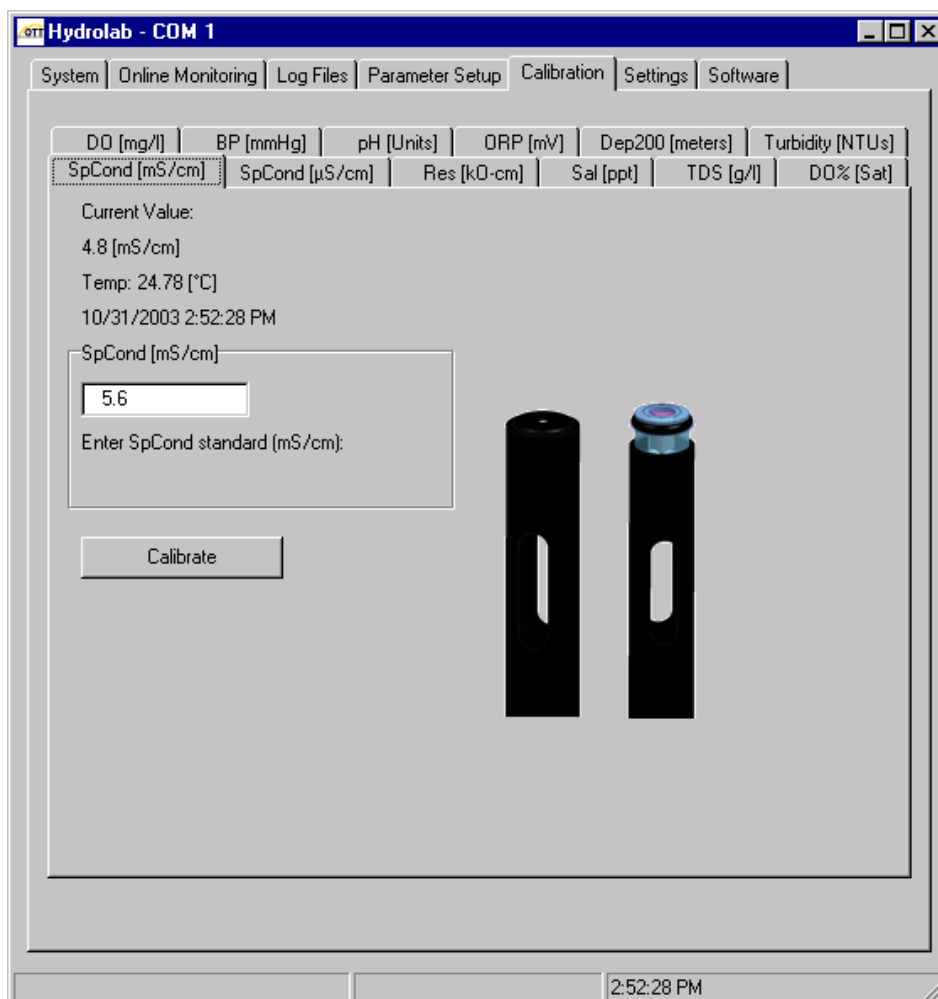
4.2.2 Calibrating the Sensors Using Hydras 3 LT

For more information on Hydras 3 LT, refer to the Quick Start Guide (Cat. No. 6234289) or press the F1 key while Hydras 3 LT is active.

1. Attach the power and data cable to the Sonde. Attach the 9-pin connector to a PC.
2. Start Hydras 3 LT. Wait for the software to scan for connected Sondes. Highlight the multiprobe and press **OPERATE SONDE**.

Note: If the Sonde appears to be connected and the software does not recognize the Sonde connection, remove and replace the connector cable and press **RE-SCAN FOR SONDE**. Repeat until Hydras 3 LT recognizes the Sonde.

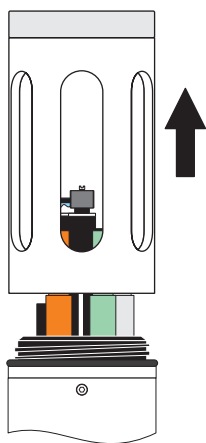
3. Click on the Calibration Tab and click on the parameter to be calibrated.
4. Enter the calibration values and click **CALIBRATE**.



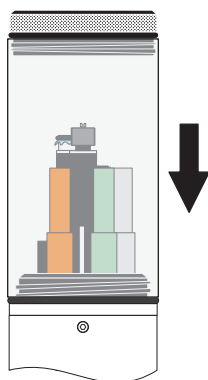
4.2.3 Calibration Preparation

The following is a general outline of the steps required to calibrate all the sensors.

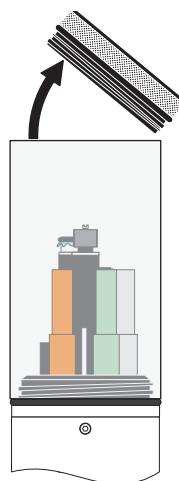
- Select a calibration standard whose value is near the field samples.
- Clean and prepare the sensors.
- To ensure accuracy of calibration, discard used calibration standards appropriately. Do not reuse calibration standards.



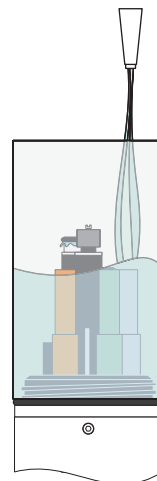
1. Remove Sensor Guard.



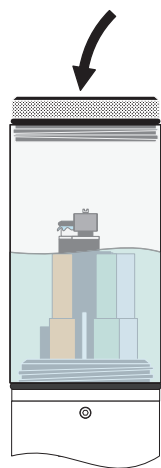
2. Attach the Calibration Cup.



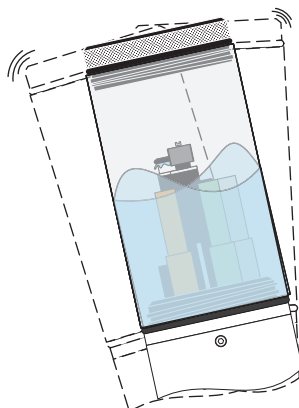
3. Unscrew and remove the cap from the Calibration Cup.



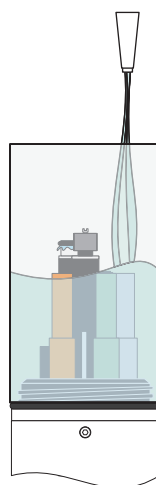
4. Fill the Calibration Cup half-full with deionized water.



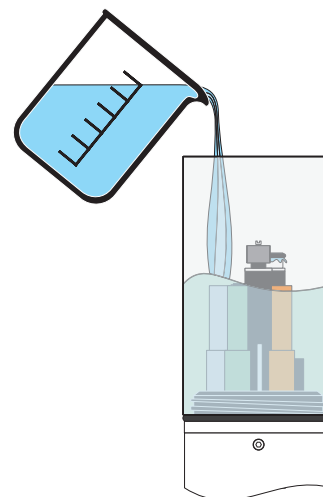
5. Place the Cap on the Calibration Cup.



6. Shake the Sonde to make sure each sensor is free from contaminants that might alter the calibration standard. Repeat several times.



7. In a similar manner, rinse the sensors twice with a small portion of the calibration standard, each time discarding the rinse.



8. Complete the calibration.

4.2.4 Temperature Sensor Calibration

The temperature sensor is factory-set and does not require recalibration.

4.2.5 Specific Conductance Calibration

Note: TDS measurements are based on specific conductance and a user-defined scale factor. The factory default scale is 0.64 g/L / mS/cm.

This procedure calibrates TDS, raw Conductivity, and Salinity. Specific conductance requires a two-point calibration. Calibrate the sensor to zero and then to the slope buffer.

1. Pour the specific conductance standard to within a centimeter of the top of the Calibration Cup.
2. Make sure there are no bubbles in the measurement cell of the specific conductance sensor.
3. Enter the SpCond standard for mS/cm or μ S/cm using Hydras 3 LT software or a Surveyor.

4.2.6 Clark Cell Dissolved Oxygen Sensor Calibration

Dissolved oxygen calibrations can be performed using water-saturated air or using a water sample with a known dissolved oxygen concentration.

Note: Dissolved oxygen can also be calibrated in a well stirred bucket of temperature-stable, air-saturated water. This situation resembles the actual field measurement conditions, but is more difficult to accomplish reliably.

4.2.6.1 Water-Saturated Air Dissolved Oxygen Calibration

CAUTION

The saturated-air method is valid only for the Clark Cell dissolved oxygen sensor. If calibrating the Hach LDO sensor, refer to the Hach LDO Instruction Sheet (Cat. No. 00745589).

Note: Calibration of D.O. % Saturation also calibrates D.O. mg/L.

1. Fill the Calibration Cup with deionized or tap water (specific conductance less than 0.5 mS/cm) until the water is just below the membrane O-ring. Do not allow water to contact the membrane or the O-ring.
2. Carefully remove any water droplets from the membrane with the corner of a tissue.
3. Turn the black cap upside down (concave upward) and lay it over the top of the Calibration Cup. This stops the exchange of air and allows the local environment to equilibrate. Wait for the reading to stabilize.
4. Determine the true barometric pressure for entry as the calibration standard. Barometric pressure information can be obtained from a local weather station or airport or the Surveyor (if equipped with BP). Some facilities calibrate BP at sea level, an elevation correction will need to be made.

Local Barometric Pressure, BP, in mmHG can be estimated using:

$$BP' = 760 - 2.5(A_{ft}/100) \quad \text{or} \quad BP' = 760 - 2.5(A_m/30.5)$$

where:

BP' = Barometric Pressure at altitude

BP = Barometric Pressure at sea level

A_{ft} = Altitude in feet

A_m = Altitude in meters

If using the local weather bureau BP, remember these numbers are corrected to sea level. To calculate the uncorrected atmospheric pressure BP', use on the following equations:

$$BP' = BP - 2.5(A_{ft}/100) \quad \text{or} \quad BP' = BP - 2.5(A_m/30.5)$$

where:

BP' = Barometric Pressure at altitude

BP = Barometric Pressure at sea level

A_{ft} = Altitude in feet

A_m = Altitude in meters

Local barometric pressure in mbar (BPmbar) can be converted to local barometric pressure in mmHG (BPmmHg) using:

$$BPmmHg = 0.75 \times BPmbar$$

5. Enter the barometric pressure in millimeters of Mercury (mmHg) at the site using Hydras 3 LT software or a Surveyor.

4.2.6.2 Known Concentration Dissolved Oxygen Calibration

Note: Calibration of D.O. mg/L also calibrates D.O. % Saturation.

1. Immerse the sensor in a water bath for which the D.O. concentration in mg/L is known (for instance, by Winkler titration). This calibration method is more difficult to perform than the saturated-air method but can yield a higher accuracy if the "known" D.O. concentration is highly accurate.
2. Enter the barometric units (mmHg) using Hydras 3 LT or a Surveyor.
3. Enter the D.O. units in mg/L using Hydras 3 LT or a Surveyor.

Note: If there is a change in barometric pressure after calibration (for instance, if barometric pressure drops as you move the calibrated Transmitter to a higher elevation for deployment), the readings for D.O. % Saturation will not be correct. You must enter a new barometric pressure. However, the readings for D.O. mg/L will be correct regardless of changes in barometric pressure.

4.2.7 Pressure Sensor Calibration

Note: The density of water varies with specific conductance. Pressure readings are corrected for specific conductance.

1. Remove water from the calibration cup.
2. Point sensors down.
3. Enter zero for the standard using Hydras 3 LT or a Surveyor.

4.2.8 pH/ORP Calibration

1. Pour the pH or ORP standard to within a centimeter of the top of the cup.
2. Enter the units for pH or ORP using Hydras 3 LT or a Surveyor.

Note: pH is a two-point or three-point calibration. A pH standard between 6.8 and 7.2 is treated as the “zero” and all other values are treated as the “slope”. First calibrate “zero”, then calibrate “slope”.

After the sensors have been properly maintained, the sensors can be calibrated. Always allow sufficient time for thermal stabilization of the standards. To reduce the time for stabilization, try to keep all calibration standards and equipment stored at the same temperature before parameter calibration. Always use fresh standard and do not tamper with standards.

4.2.9 Other Sensor Calibrations

Refer to the sensor specific instruction sheet for more information.

4.3 Using the DS5/MS5 for Short Term Deployments

4.3.1 Gathering Data Using the Surveyor

Refer to the Surveyor Manual (Cat. No. 003070).

4.3.2 Gathering Data Using a PC and Hydras 3 LT

For online monitoring and real-time monitoring information, refer to the Hydras 3 LT Quick Start Guide (Cat. No. 6234289).

4.3.3 Using the DS5/DS5X/MS5 for Unattended Monitoring

4.3.3.1 Creating Log Files

Note: A log file must be created and then enabled before data can be collected.

1. Connect the Data Cable to a computer and to the Sonde.
2. Start Hydras 3 LT. The software will automatically scan for Sondes. All detected Sondes are displayed in the ‘Connected Sondes’ list in the Main window displayed below. If a Sonde is not found, reattach the data cable and press **RE-SCAN FOR SONDES**. Retry until the Sonde(s) are found.
3. Click on the Log Files tab.
4. Click the **CREATE** button.

5. Enter the name for the new log file. The empty log file is now created.
6. Enter the start and end time of the logging, the logging interval, the sensor warm-up time before logging, and how long before logging the circulator will be turned on, and if audio signals will be used while logging.
7. Select the parameters in the 'Parameter in Sonde' list and click the **ADD** button to place them into the 'Parameters in log file' list. Change the order of the parameters using the **ARROW** buttons.
8. Click **UPDATE SETTING** to send the configuration to the Sonde.
9. Click **ENABLE** to start collecting data. Click **DISABLE** to stop collecting data during logging. A fully completed logging run will automatically disable at the end of the run.
10. Click **DOWNLOAD** to download and display the log file. Select Printable or Spreadsheet format.

***Note:** To delete a log file, select the log file in the Log File drop-down menu and click the **DELETE** button.*

4.3.3.2 Downloading Log Files

After a log file is created in the Log Files tab, the files can be downloaded by checking the appropriate Log File box and clicking **DOWNLOAD SELECTED FILES**. Multiple files can be downloaded at once. The downloaded log files are stored in the 'LogFiles' subdirectory of the HYDRAS 3 LT directory on the hard drive.

Section 5 Deployment

5.1 Deployment Considerations

5.1.1 Pressure Extremes

Note: The multiprobe maximum immersion depth is 225 meters (738 feet).

Note: The ion specific sensors (Nitrate, Ammonia, and Chloride) maximum deployment depth is 15 meters.

Important Note: The 0–10 meter vented depth sensor should be protected from depths over 15 meters (49 feet) by installing the seal screw (provided in the basic maintenance kit) in the face of the multiprobe sensor cap. Likewise, the 0–25 depth sensor should be protected from depths over 35 meters (164 feet) by installing the same seal screw. However, the 100- and 200-meter depth sensors do not require installation of the seal screw.

The multiprobe may be equipped with one of the following depth options: 0–10 meters (33 feet), 0 to 25, 0 to 100, and 0 to 200 meters (82, 328, and 656 feet). The first option is used to detect water level changes that are automatically compensated for barometric pressure changes. Applications include tidal waters, rivers, stream, lakes, reservoirs, and groundwater. The vented level option must have a fixed cable with a vent tube. The second, third, and fourth options are usually used to determine the depth in the water column at which the other parameter readings are made.

5.1.2 Temperature Extremes

The multiprobe storage temperature range is 1 to 50 °C (34 to 122 °F), non-freezing, when going or coming back from a deployment site, or when storing the multiprobe.

The multiprobe operating temperature range is –5 to 50 °C (23 to 122 °F), non-freezing. Exposing the multiprobe to temperatures outside this range may result in mechanical damage or faulty electronic performance.

To prevent sensors from freezing, store the multiprobe where freezing will not occur. To prevent the sensors from dehydrating, fill the DS storage cup or MS cup with one inch of clean tap water.

Always rinse the multiprobe with clean tap water after deployment.

5.1.3 Data Transmission Lines

When adding a transmission cable to the multiprobe, the cable must be large enough to carry the operating current and transfer data without distortion. For up to a total of 305 m (1000 ft) of cable, three 26 AWG wires are suitable for data transmission, but two 18 AWG must be used for the power wires. Alternatively, smaller power wires can be used if the power supply is placed closer to the multiprobe. A cable extension kit is available for above-ground applications ([Replacement Parts and Accessories on page 47](#)).

5.1.4 Minimum Depth Requirements

Sensors must be immersed. The Standard Turbidity Sensor minimum deployment depth is 1 meter.

5.2 Deployment in Open Waters

5.2.1 Minimum Clearance Requirements

Two inches of clearance is required from the longest probe and two inches around if a Turbidity sensor is supplied.

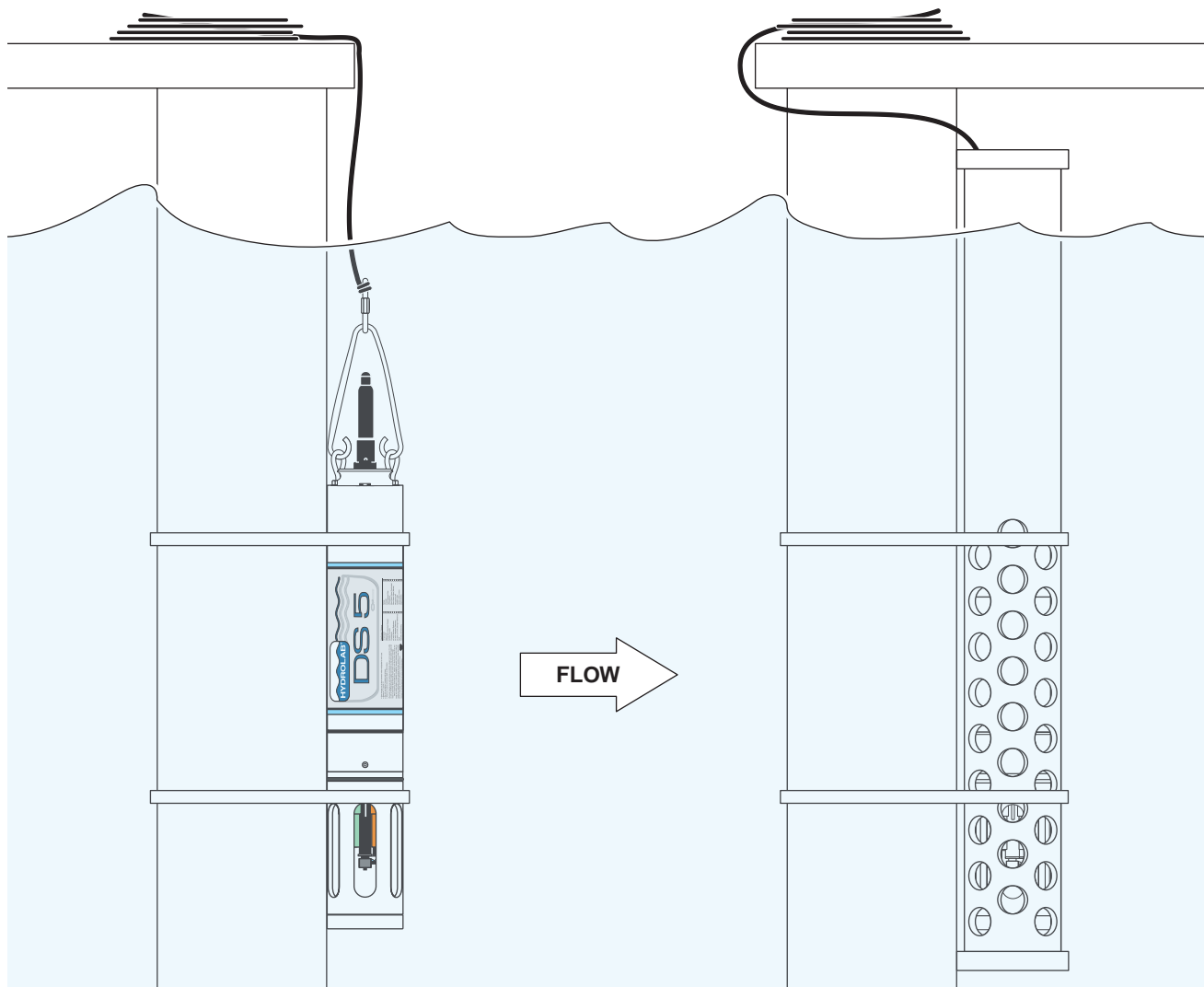
5.2.2 Long-term Deployment in Open Waters

Important Note: The use of pipe clamps to secure the Sonde can cause serious instrument damage.

When using the multiprobe in open water, place the multiprobe where it will not get damaged. For example, to protect the multiprobe from being hit by floating debris in moderate-to high-flow levels, anchor the multiprobe to the downstream side of a bridge piling (Figure 7). The protection kit can also be used to protect the multiprobe. In a recreational lake deployment, use a marking buoy that will not attract vandalism.

Place the multiprobe in an upright or on-side position, and avoid areas with deposits of sand, gravel, or silt during heavy rainfall. Avoid deploying in location where ice will form around the sensors or Sonde.

Figure 7 **Securing the Multiprobe to a Structure**



When securing the multiprobe to a structure, carefully place straps such as web belts and large plastic Ty-wraps on both ends of the multiprobe housing ([Figure 7](#)). Do not use clamps to secure the multiprobe to a structure. Also, secure the cable in the same manner to protect it from floating debris, navigation, and vandalism.

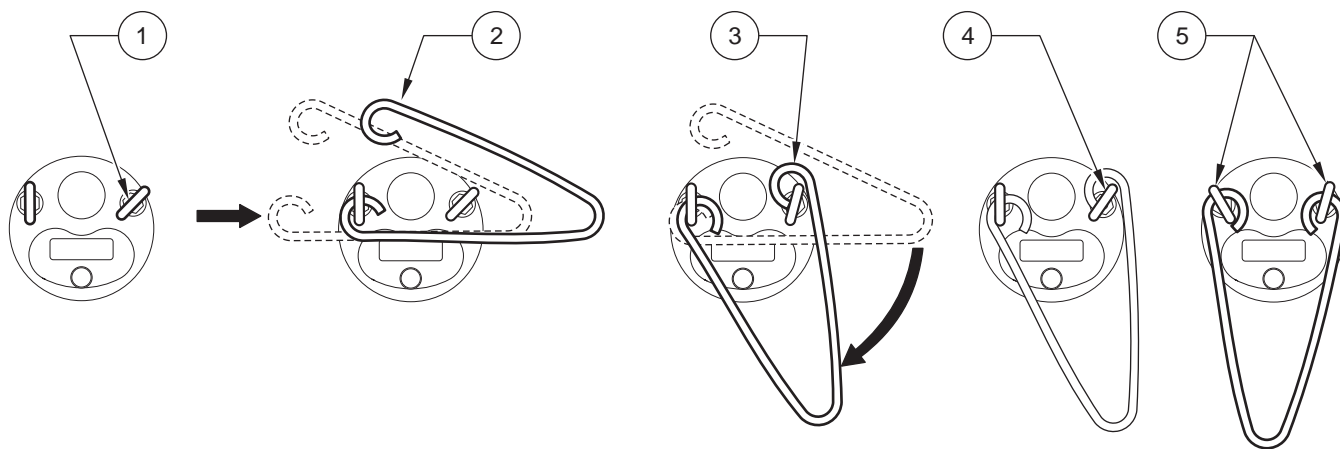
Always make sure the weighted sensor guard is installed to protect the sensors and provide additional sinking weight to the multiprobe.

Calibration stability is dependent on the environmental conditions in which the sonde is deployed. For example, a D.O. sensor on a DS5 or MS5 may become fouled if deployed in a warm, shallow, biologically active lake. However, deployment length can be increased by a factor of 5 by using a DS5X which periodically cleans the fouling from the sensors. On the other hand, the same sonde deployed in a clean water environment, or a sonde configured with sensors impervious to fouling (i.e., Temperature, Conductivity) can be left unattended for months without the need to recalibrate. Optimal deployment time for a specific environment can be determined by making periodic measurements of sensitive parameters with another instrument.

5.2.2.1 Anchoring the DS5 or DS5X using the Support Bail

1. Run a rope or chain through the bail, if the Sonde is equipped with a support bail.
2. Fix the bail into the two eyebolts on the top of the Sonde by first loosening the lock-nuts and turning the eyebolt 90°, and then back, so that the bail can be looped through.
3. Securely tighten the lock-nut on each eyebolt. If the multiprobe is not equipped with internal batteries, it may not have a bail but can be secured using the locking sleeve.

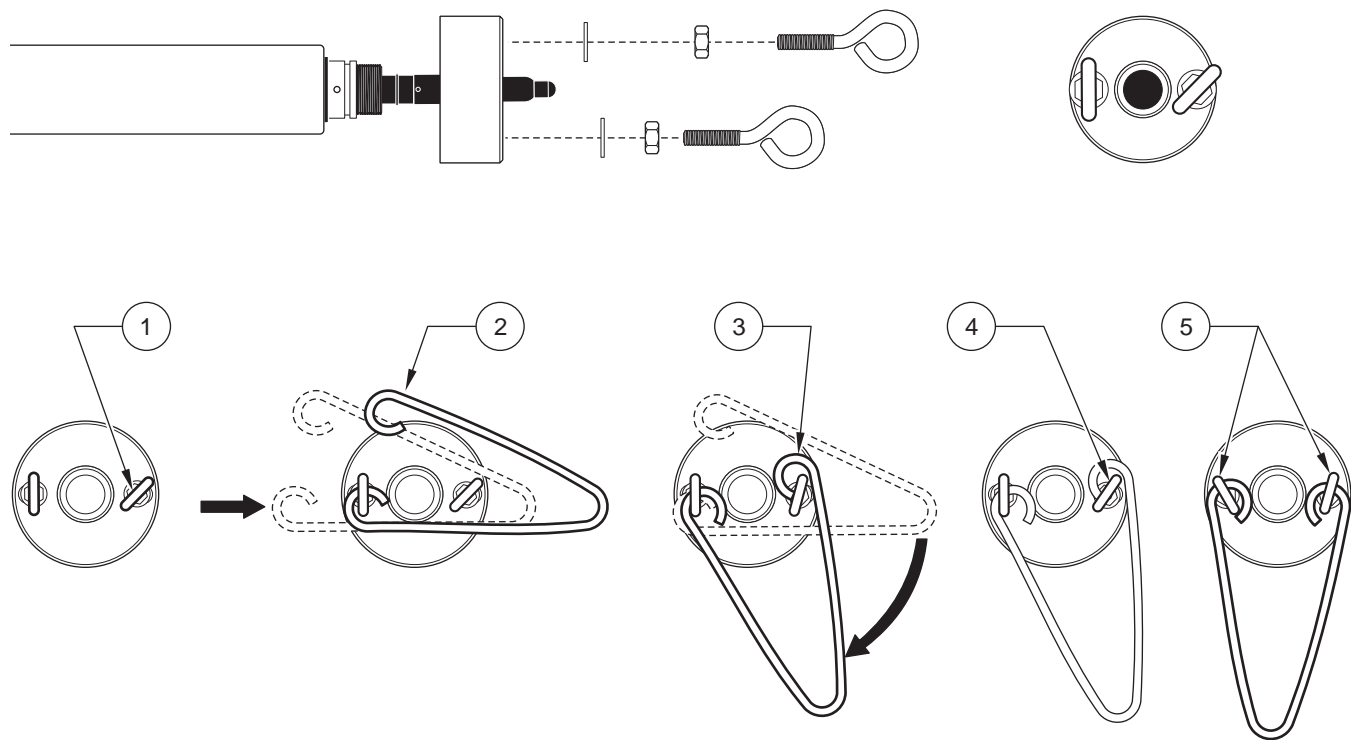
Figure 8 DS5 Support Bail Installation



1. Turn the eye bolts to the positions shown.	4. Rotate the eye bolt around the bail as shown.
2. Hook the bail into the eye bolt as shown.	5. Finish rotating the eye bolts until the bail cannot be removed.
3. Rotate the bail into the other eye bolt as shown.	

5.2.2.2 Anchoring the MS5 using the Bail Kit

Figure 9 MS5 Support Bail Installation

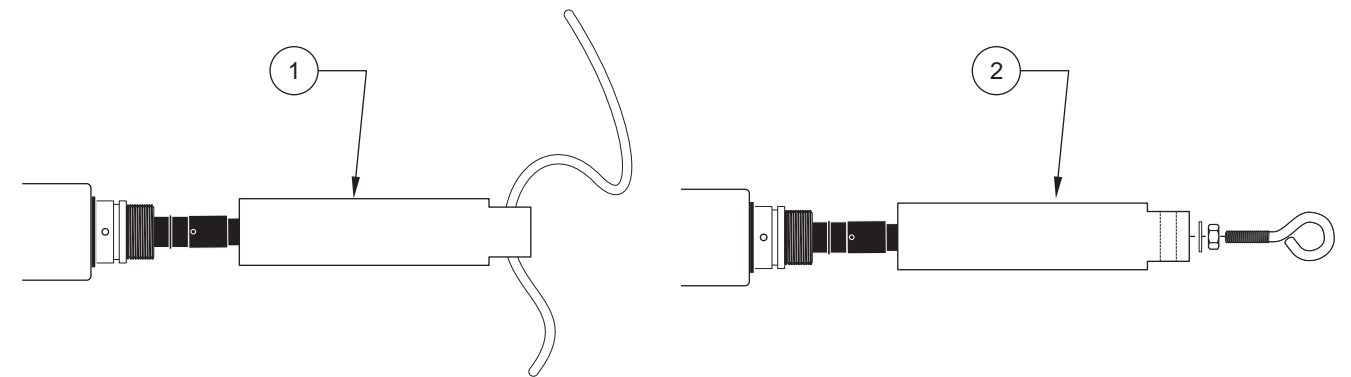


1. Turn the eye bolts to the positions shown.	4. Rotate the eye bolt around the bail as shown.
2. Hook the bail into the eye bolt as shown.	5. Finish rotating the eye bolts until the bail cannot be removed.
3. Rotate the bail into the other eye bolt as shown.	

5.2.2.3 Anchoring the MS5 using the Mooring Fixture

A MS5 equipped with an internal battery pack requires the MS5 mooring fixture which screws onto the multiprobe bulkhead connector and provides an eyelet for rope or wire when no cable is used during deployment.

Figure 10 MS5 Mooring Fixture



1. Mooring fixture used with rope or chain.	2. Mooring fixture used with eye bolt.
---	--

5.2.3 Short-term Deployment in Open Waters

Generally, short-term deployment implies hand-held operation.

Important Note: Do not pull Sonde from a moving boat or instrument damage may occur and voids the instrument warranty.

- Do not lower the multiprobe into the water without screwing on the weighted sensor guard.
- Secure the underwater cable prior to deployment.
- Do not place the instrument where the cable might be severed or damage by boat propellers or any moving parts on a monitoring system.
- Protect all cables from abrasion, unnecessary tension, repetitive flexure, or bending over sharp radii (boat gunwale or a bridge railing).
- Do not bend or run the cable over the sheave or pulleys with less than 3-inch radius or 6 inches in diameter.
- Use the V-shaped support bail to lift and lower the multiprobe, if so equipped. This ensures that the weight of the multiprobe is suspended from the bail. If the multiprobe is equipped with a locking sleeve instead of a support bail, make sure the locking sleeve or the MSS mooring fixture are properly screwed on the multiprobe 6-pin marine bulkhead connector before deployment.
- Extra weight, up to 5 kg (10 lb) maximum, can be attached to the Sonde (Figure 11). If more weight is needed, use a wire line to support the instrument by its bail, if so equipped.
- Use a battery-powered or hand-cranked reel with electrical slip-rings to lower and raise the instrument, if the cables are very long. A lighter reel without slip-rings for shorter cables can also be used (Figure 12).
- If sufficient deck space permits, mount the reel horizontally with the instrument and a battery installed in the hub (Figure 12). The manufacturer's cable reel can also be used to store up to 150 m (490 ft) of underwater cable (the reel must be ordered with the initial underwater cable purchase).
- In deep deployments currents, in conjunction with the sensor guard, can put extreme strains on the cabling.

Figure 11 Using the Weighted Sensor Guard

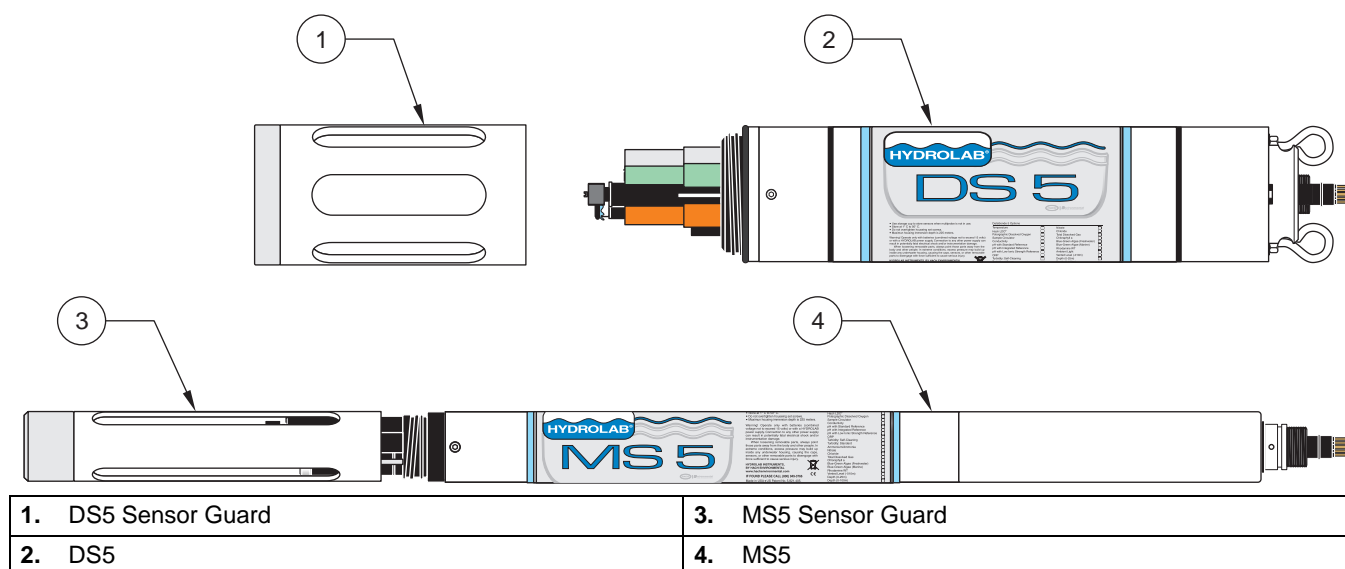
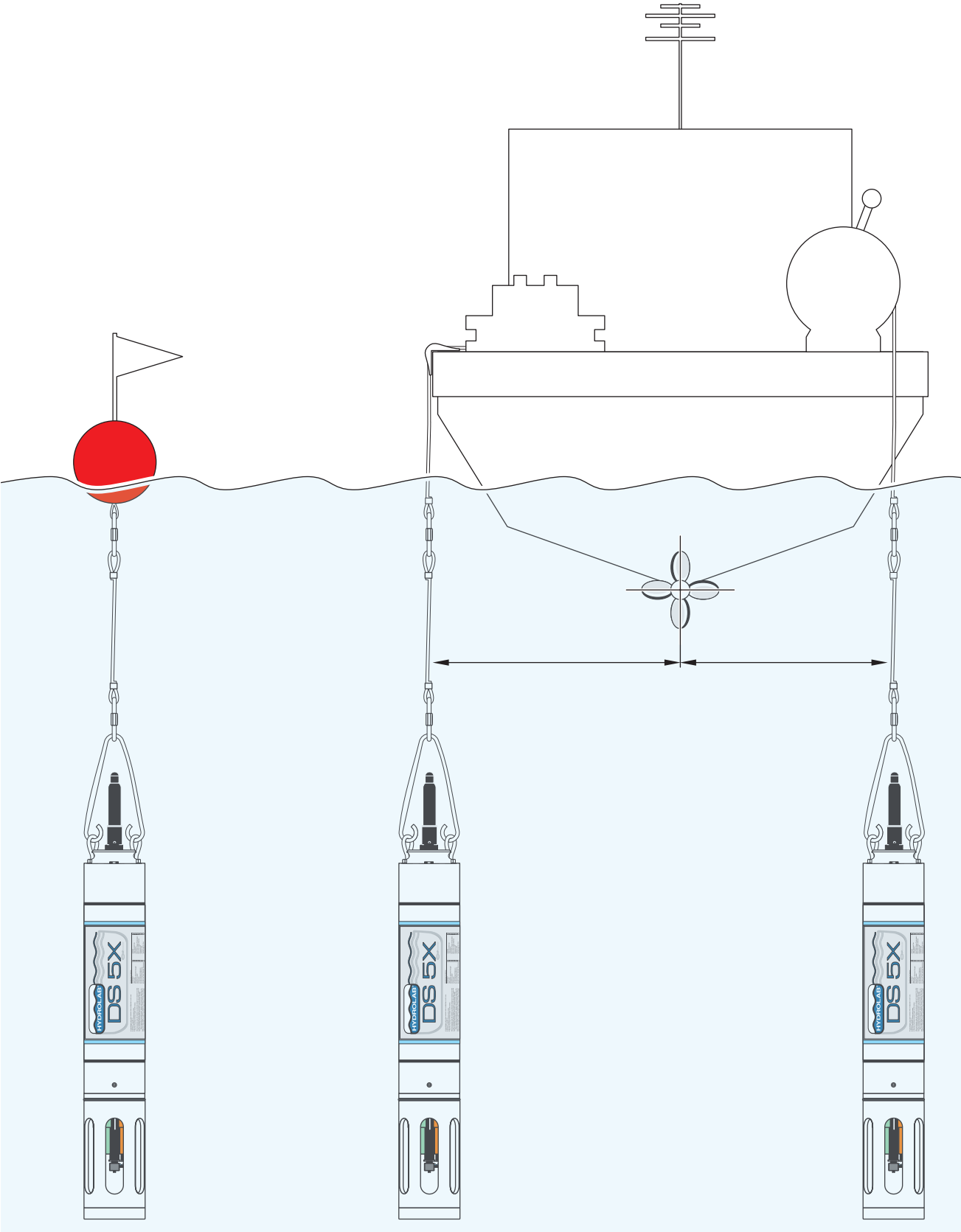


Figure 12 Open Water Deployment



5.2.4 Minimum Flow Requirements

When deploying the multiprobe in waters flowing at less than one foot per second (0.333 mps), a circulator option may be used for additional flow in order to achieve reliable Clark Cell dissolved oxygen sensor readings. The circulator is activated via Hydras 3 LT software or the Surveyor.

Turning the circulator on or off will help during profiling and logging D.O. with a Clark Cell Sensor, depending on the flow rate of the water at the site. If insufficient flow rate is noticeable, turn the circulator on. Turn the circulator off to extend battery life when data is not needed for an extended period of time. Turn the circulator on when logging data in unattended mode and need to have sufficient flow for accurate measurements, note that this will reduce multiprobe battery life.

When the multiprobe is powered, it takes time to warm-up. The warm-up time refers to the time a sensor will be ready to record accurate data. Warm-up time will vary according to the sensors being used and field conditions (e.g. temperature).

5.2.5 Non-submersible Deployment

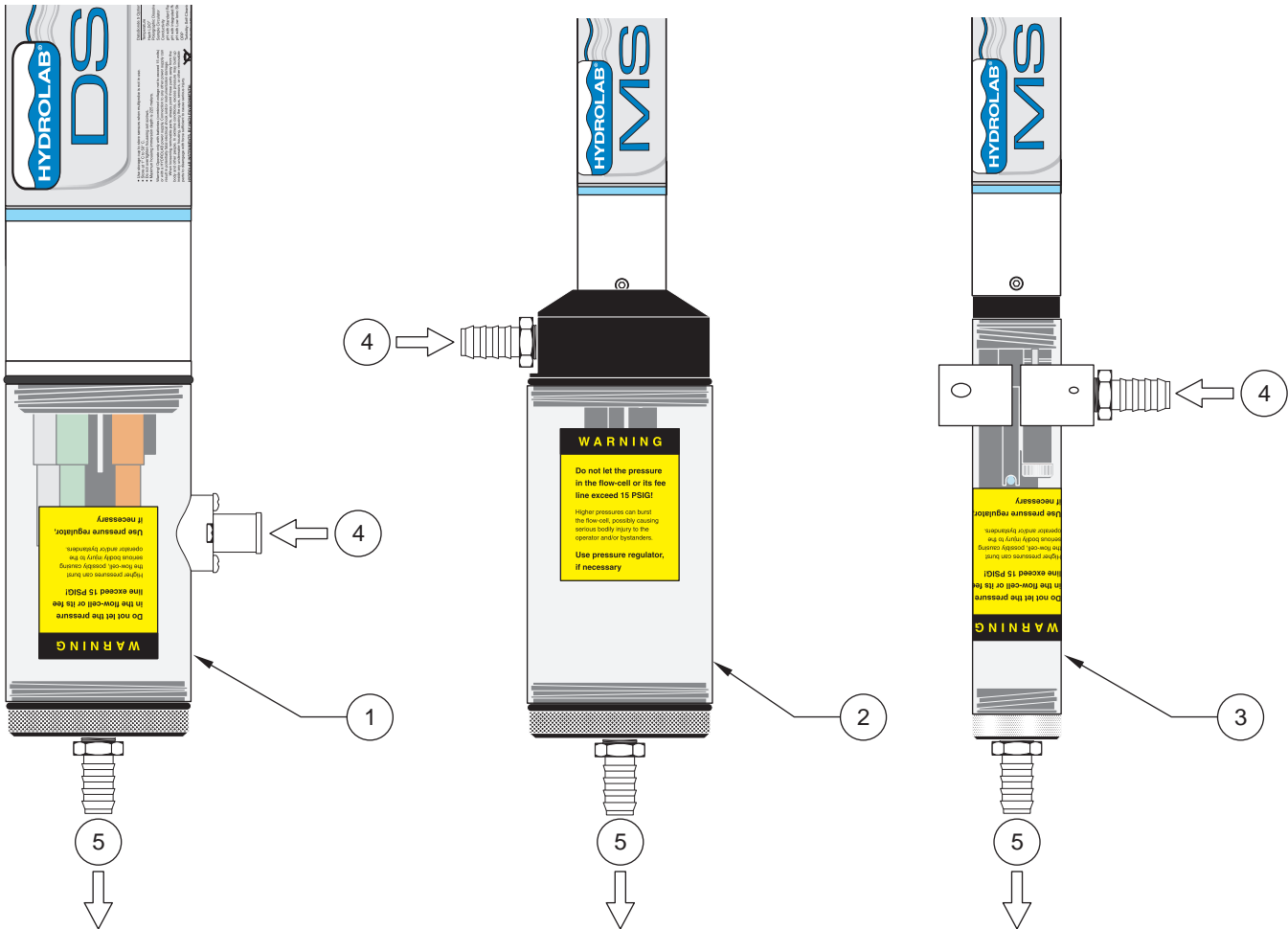
DANGER

Do not let the flow cell pressure exceed 15 psig. Higher pressure can burst the flow cell, possibly causing serious bodily injury to oneself and/or others.

For process or pump-through situations, attach the low-pressure flow-cell to the multiprobe. This configuration allows studying the water without submerging the multiprobe. The flow cell replaces the DS storage cup or MS cup ([Figure 13](#)). When measuring D.O. with a Clark Cell Sensor inside a flow cell, the manufacturer recommends using a circulator in conjunction with the sensor. For use without a circulator, use a flow rate of more than 4 liters per minute. A ½-inch hose is required for the MS flow cell and a ¾-inch hose for the DS flow cell.

Filter debris from the feed line, if necessary. If possible, invert the multiprobe, so that bubbles will float away from the sensors and out the port on the bottom of the flow cell.

Figure 13 Flow Cells



1. DS flow cell	4. Sample flow IN
2. MS flow cell (with standard turbidity sensor)	5. Sample flow OUT
3. MS flow cell	

DANGER

Only qualified personnel should conduct the maintenance tasks described in this section of the manual.

To ensure continued and reliable operation of the water quality monitoring system, we recommend scheduling a thorough and regular maintenance program. To determine the appropriate maintenance intervals required for a deployment site, periodically conduct a visual inspection of the equipment and sensors, compare the pre- and post-calibration results, and monitor the sensor response time.

A contaminated, worn-out, or damaged sensor will not produce reliable readings. It is recommended to service all sensors and allow them to equilibrate in tap water overnight before calibration.

Maintenance kits are available for the DS5, DS5X, and MS5. See [Replacement Parts and Accessories on page 47](#).

6.1 Multiprobe and Accessory Maintenance

6.1.1 Cleaning the Multiprobe Housing

Clean the outside of the multiprobe housing using a clean brush, soap, and water. Always use the DS storage cup or the MS cup (filled with one inch of tap water) to protect the sensors from damage, and especially from drying out, whenever the multiprobe is not deployed.

Do not expose equipment to extreme temperatures below 1 °C (34 °F) or above 50 °C (122 °F).

Always rinse the multiprobe with clean tap water soon after returning from deployment.

6.1.2 Dryer Maintenance

Important Note: Do not submerge the dryer in water.

The in-line vented level dryer is a part of the cable and penetrator assembly, if the Sonde has the vented depth sensor (0–10 meters).

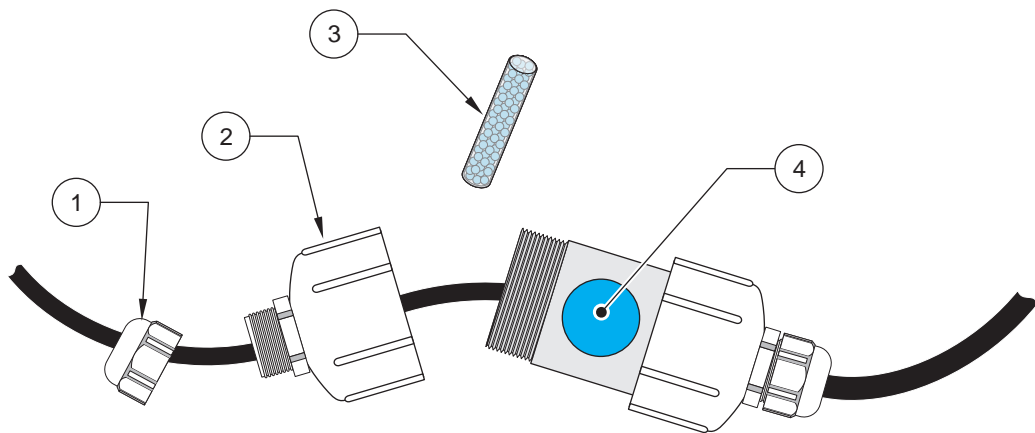
The GORE-TEX® patch (round patch on dryer) allows gases to come into the dryer and is splash proof, but not submersible. Any water leaks inside the dryer can block the tube which goes into the multiprobe. If water leaks are detected, contact Technical Support.

The dryer contains desiccant bag(s) (white bag) to keep condensation from forming inside the vented tube which goes from the dryer to the multiprobe. If moisture is detected inside the dryer, replace the bags ([Figure 14](#)).

To replace the desiccant bag(s):

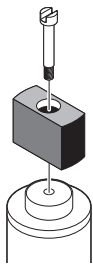
1. Unscrew both dryer nuts and unscrew the dryer cap.
2. Inspect the indicator strip. If the stripe is dark blue, the bag does not need replacement. If the stripe is light pink or purple, remove, discard, and replace the old bag.
3. Reassemble the dryer.

Figure 14 Dryer Maintenance



1. Dryer Nuts (2)	3. Desiccate Packet
2. Dryer Cap	4. Gore-tex Patch

6.1.3 FreshFlow™ Miniature Sample Circulator Maintenance



1. If the circulator is clogged with twigs or other small debris, clean the impeller with some tap water using a soft bristle brush. Use a pair of plastic tweezers to help remove debris. Rinse with tap water.
2. If there is excessive build-up on the impeller, remove the retaining screw to clean the build-up. After cleaning the impeller, and before inserting the retaining screw, apply a very small amount of Loctite™ 242 threadlock (or equivalent) on the tip of the screw. Do not overtighten.

6.2  Battery Replacement

If the multiprobe is equipped with an internal battery pack, the following batteries are customer-replaceable. The Sondes are also equipped with a customer-replaceable Lithium clock battery.

- 8 size C alkaline batteries for the DS5 and DS5X
- 8 size AA alkaline batteries for the MS5

Important Note: To keep internal components dry, avoid replacing batteries near a water source.

Important Note: If water leaks into the multiprobe battery compartment, remove the batteries, pour the water out, and thoroughly dry the compartment with a towel.

6.2.1  DS5 and DS5X Battery Replacement

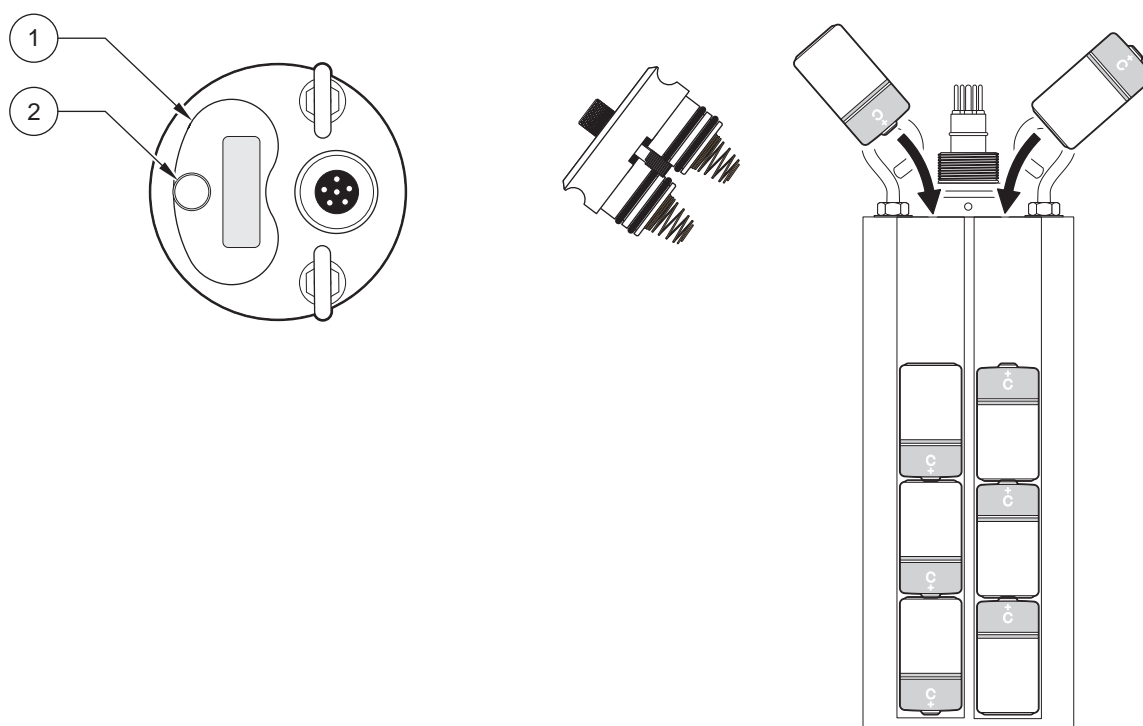
DANGER
If the thumbscrew is difficult to remove, there may be pressure built up inside the housing. To avoid serious injury, use extreme caution when loosening the battery cap thumbscrew.

DANGER
Batteries must be installed in the correct orientation or serious injury and instrument damage may occur. Do not mix depleted and fresh batteries together or serious injury and instrument damage may occur.

Use only high quality, non-rechargeable batteries in the DS5 or DS5X multiprobe. Refer to [Figure 15](#) and the following directions for DS5 and DS5X battery replacement.

1. Set the multiprobe horizontally on the work surface to prevent water leaking into the multiprobe battery compartment.
2. Unscrew the battery cap thumbscrew, counterclockwise.
3. Pull the cap out of its housing and slide the old batteries out.
4. Discard the old batteries. Insert the new batteries, **observing polarity markings located on the inside label**. Failure to install the batteries in the correct orientation may cause serious injury and instrument damage.
5. Coat the battery cap O-rings sparingly with silicone grease. Insert the cap back into the multiprobe housing. Tighten the thumbscrew, clockwise. Finger-tighten only.

Figure 15 DS5 and DS5X Battery Replacement



1. Battery Cap

2. Battery Cap Screw

6.2.2



MS5 Battery Replacement

DANGER

Batteries must be installed in the correct orientation or serious injury and instrument damage may occur.

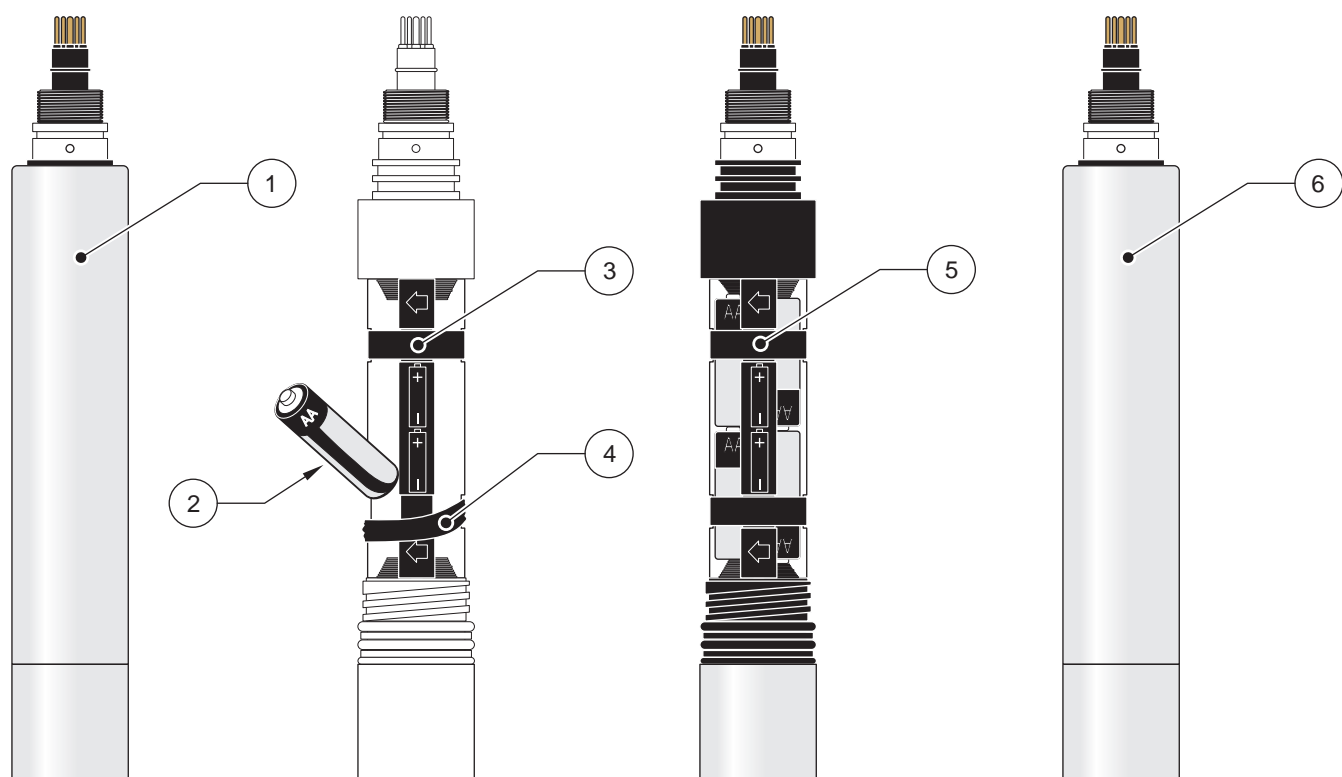
DANGER

Do not mix depleted and fresh batteries together or serious injury and instrument damage may occur.

1. Set the multiprobe horizontally on the work surface to prevent water leaking into the multiprobe battery compartment.

- 2. Unscrew the battery sleeve. Slide the battery sleeve off of the Sonde.
- 3. Discard the old batteries. Insert the new batteries, **observing polarity markings located on the inside label**. Failure to install the batteries in the correct orientation may cause serious injury and instrument damage.
- 4. Secure the new batteries with the top and bottom rubber bands (Figure 16).
- 5. Coat the battery sleeve O-rings sparingly with silicone grease.
- 6. Screw the battery sleeve back on the Sonde. Do not overtighten or instrument damage will occur.
- 7. Discard batteries according to local regulations.

Figure 16 MS5 Battery Replacement



1. Remove the Battery Sleeve	4. Bottom Retaining Rubberband
2. Remove depleted AA Batteries	5. Proper Battery Placement
3. Top Retaining Rubberband	6. Replace the Battery Sleeve

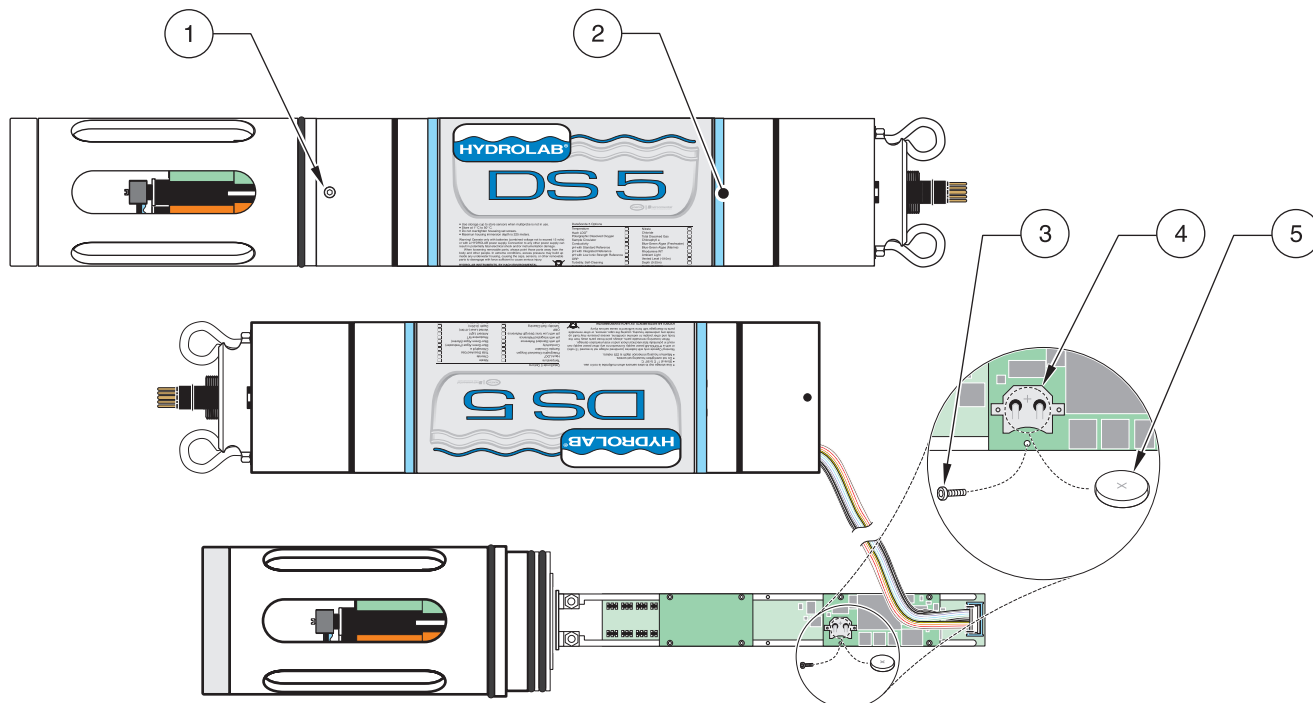
6.2.3 Lithium Battery Replacement

The typical replacement period for the lithium battery is once every two years. The lithium battery powers the real-time clock that provides accurate time readings during datalogging. Refer to Figure 17 and Figure 18 and the following instructions for proper lithium battery replacement.

- 1. Remove the Allen screws with the Allen wrench to remove the multiprobe sensor cap. To help remove the Sonde sensor cap, insert the screwdriver head into the notches on the multiprobe housing at the bottom of the sensor cap.

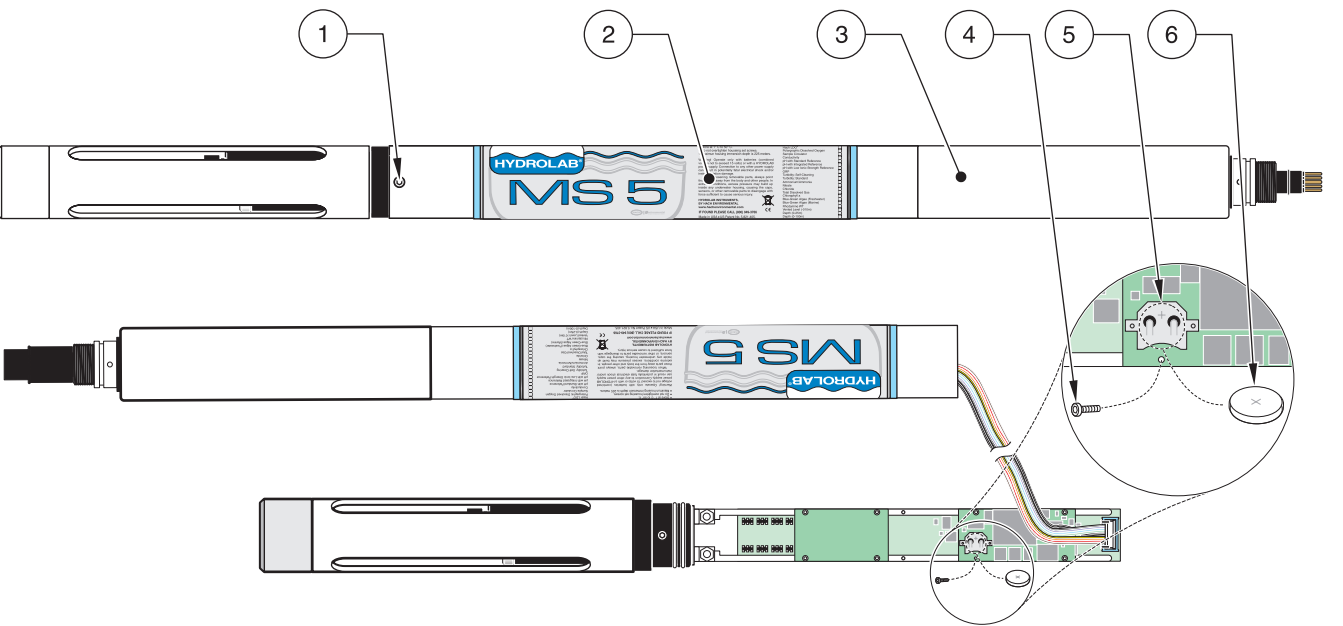
2. Remove the Sonde body, then slide the sleeve off of the Sonde. Avoid damage to the circuit board.
3. Carefully remove the foil shield.
4. Detach the 10-pin connector ribbon cable.
5. Remove the retaining screw next to the battery clip (Figure 17 and Figure 18).
6. Push the battery out of the battery clip using a small screwdriver.
7. Insert the new battery (Panasonic reference: CR 2032, or equivalent) with the positive sign facing up. Replace and tighten the retaining screw.
8. Reattach the 10-pin connector and replace the foil shield.
9. Apply silicone grease to the sensor cap O-rings.
10. Carefully insert the circuit board and sensor cap assembly.
11. Tighten the Allen screws. **Do not overtighten.**
12. Reset the time and date after replacing the lithium battery. Then enter the time of the location and press **ENTER**.
13. Discard batteries according to local regulations.

Figure 17 Replacing the Lithium Battery on the DS5 or DS5X



1. Allen Screw	4. Battery Clip
2. Housing	5. Lithium Battery
3. Retaining Screw	

Figure 18 Replacing the Lithium Battery on the MS5



1. Allen Screw	4. Retaining Screw
2. Housing	5. Battery Clip
3. Sonde Body	6. Lithium Battery

6.3 Storage and Care Recommendations

6.3.1 Multiprobe and Sensor Storage

- Fill the DS storage cup or MS cup with one inch of clean tap water and screw the cup on the multiprobe. To prevent sensors from freezing, store the multiprobe where freezing will not occur.
- Remove batteries for long-term storage. (8 size C alkaline batteries for the DS5 or DS5X or 8 size AA alkaline batteries for the MS5). Do not remove the lithium battery which powers the multiprobe internal clock.
- Store equipment in a carrying case (Cat. No. 011780) or a large plastic container with a circular piece of foam rubber for shock protection.
- Lay the cable in coils of at least 15 cm (6 in.) diameter at the bottom of the plastic container.

6.3.2 Electrical Cable Care

- Protect all non-waterproof cables (i.e., all cables except the waterproof underwater cable) from any water source during operation in the field. Keep connectors dry at all times.
- Properly lubricate the sealing surface of all underwater connectors using silicone grease.
- Use protective plugs when the connectors (for underwater and calibration cables) are not connected to any instrument.
- Keep all cables clean, dry, and stored (neatly coiled), in a large plastic container.
- Do not coil cables any tighter than 6 inches in diameter or cable will be damaged.

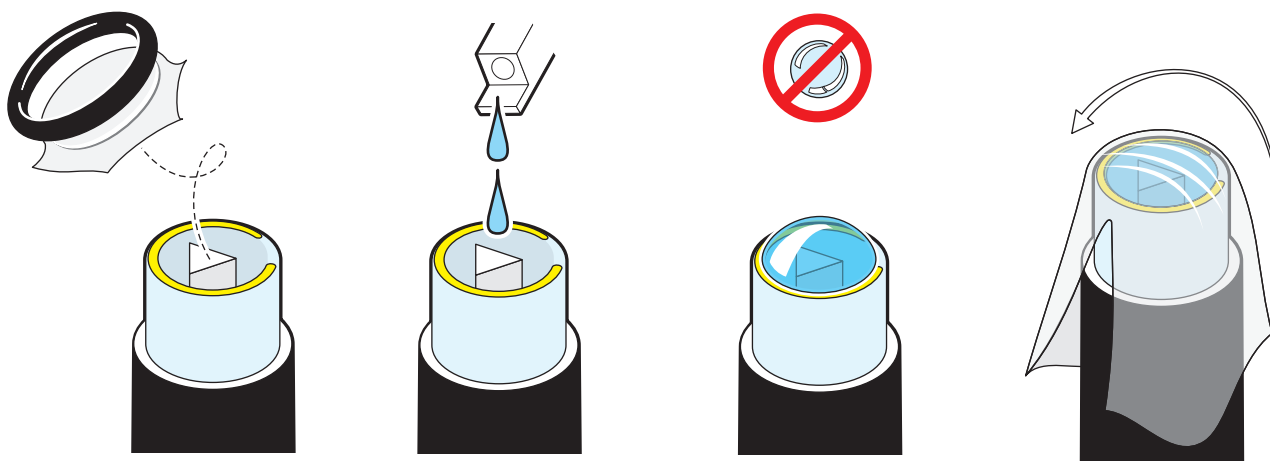
- Do not knot the cables or use clips to mark a certain depth.
- Do not place the instrument where the cable might be severed or damaged by boat propellers or other moving parts.
- Protect all cables from abrasion, unnecessary tension, repetitive flexure, or bending over sharp radii (e.g., the side of a boat or of a bridge). Do not bend or run the cable over the sheave or pulleys with less than a 6-inch diameter.
- If cables are long, use a battery-powered or hand-cranked reel with electrical slip-rings to lower and raise the instrument. Also, a lighter reel without slip-rings for shorter cables can be used. A last option, is to mount the reel horizontally with the instrument and battery installed in the hub.
- Use the V-shaped support bail to lift and lower the multiprobe.
- Do not apply more than 5 kilograms (10 lb) of sinking weight to the multiprobe. This can increase the possibility of cable breakage due to stress on the attachment points. If more weight is needed, use a wire line to support the instrument by its bail.

6.4 Sensor Maintenance

Important Note: If a sensor is not in use, insert an optional sensor expansion port plug in the vacant expansion port to prevent any contamination or damage during maintenance, operation, or storage.

6.5 Clark Cell Dissolved Oxygen Maintenance

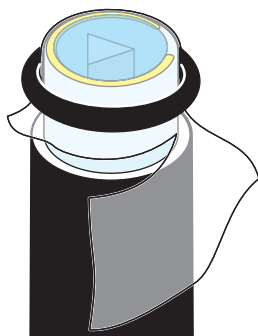
Dissolved oxygen sensor maintenance is required when the membrane covering the cell becomes wrinkled, bubbled, torn, dirty, fouled, or otherwise damaged.



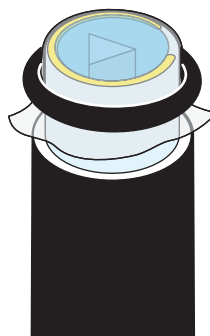
1. Remove the O-ring securing the D.O. membrane. Remove the old membrane. Shake out the old electrolyte and rinse with fresh D.O. electrolyte.
2. Refill with fresh D.O. electrolyte until there is a perceptible meniscus of electrolyte rising above the entire electrode surface of the sensor.
3. Make sure there are no bubbles in the electrolyte.
4. Hold one end of a new membrane against the body of the D.O. sensor with your thumb and with a smooth, firm motion, stretch the other end of the membrane over the sensor surface and hold it in place with your index finger.



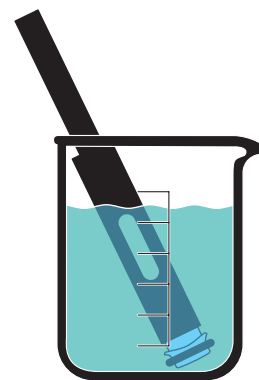
5. Secure the membrane with the O-ring. Make sure there are no wrinkles in the membrane or bubbles in the electrolyte.



6. Trim away the excess membrane extending below the O-ring.



7. Proper membrane assembly.



8. Let the sensor soak a minimum of 4 hours (90% relaxed). Ideally, the sensor should soak for 24 hours.

Note: Readings may initially drift if calibrated before the membrane is fully relaxed.

6.6 Specific Conductance, Salinity, and TDS Maintenance

Clean the oval measurement cell on the specific conductance sensor with a small, non-abrasive brush or cotton swab. Use soap to remove grease, oil, or biological growth. Rinse with water.

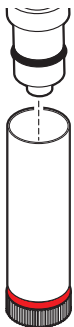
6.7 ORP Sensor Maintenance

If the platinum band or stud of the ORP sensor gets dirty and/or discolored, polish it with a clean cloth and a very mild abrasive, such as toothpaste; or use a fine polishing strip. Rinse with water. Soak the sensor overnight in tap water to allow the platinum surface to restabilize.

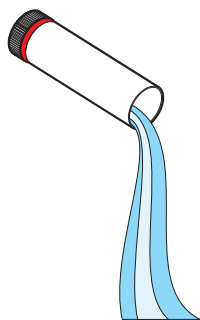
6.8 pH Electrode Maintenance

If the pH sensor is coated with oil, sediment, or biological growth, clean the glass with a very clean, soft, wet non-scratching cloth or cotton ball with mild soap. Rinse with tap water. If the pH sensor becomes dehydrated, soak for 24 hours in a pH 4 buffer solution.

6.8.1 Standard Reference Electrode



1. Gently pull the entire reference sleeve away from the Transmitter.



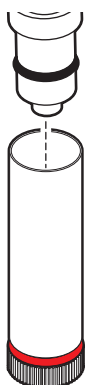
2. Discard the old electrolyte from the reference sleeve.



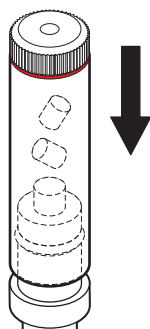
3. Drop two KCl salt pellets (Cat. No. 005376HY) into the reference sleeve.



4. Refill the sleeve to the top with reference electrolyte.



5. With the Transmitter sensors pointed down, push the full reference sleeve back onto its mount until the sleeve has just covered the O-ring located on the mount (just behind the silver electrode).

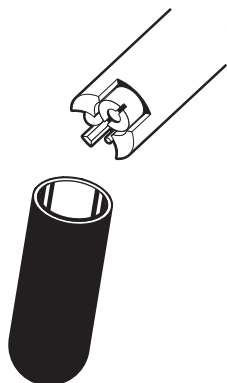


6. Turn the Transmitter so that the sensors point up and push the sleeve the rest of the way onto its mount. Rinse with tap water.

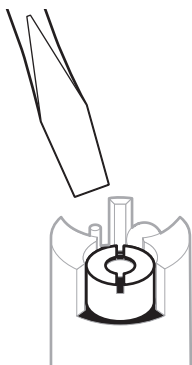
Note: The porous Teflon® Reference Junction is the most important part of the pH and ORP performance. Make sure it is clean and passes electrolyte readily. If not, replace it with the spare provided in the maintenance kit. Replacement Reference Junctions are Cat. No. 000548HY.

Note: When seating the reference sleeve, trapped air and excess electrolyte are purged. This purging flushes and cleans the porous Teflon® Reference Junction.

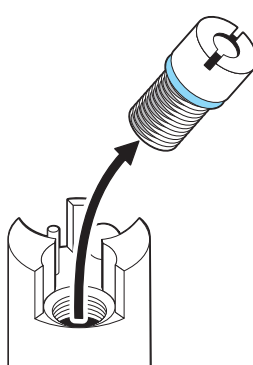
6.8.2 pH Integrated Sensor



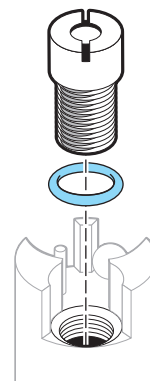
1. Remove the plastic soaking cap. Save the cap for reuse.



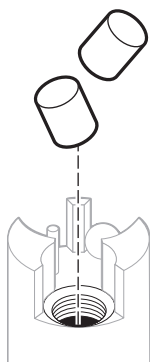
2. Use the supplied screwdriver to loosen the Teflon® Reference Junction.



3. Remove the Teflon Reference Junction and discard if dirty or clogged.



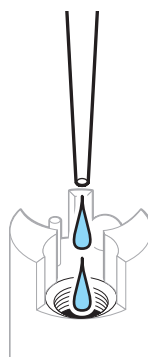
4. Replace the blue O-ring located below the Teflon Reference Junction if it is damaged or loose.



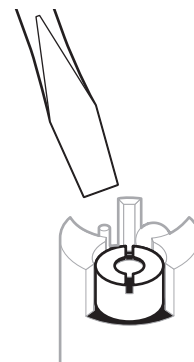
5. Drop two KCl salt pellets (Cat. No. 00537HY) into the reference opening.



6. Inject the pH reference electrolyte into the supplied plastic syringe.



7. Refill the reference opening with electrolyte.



8. Use the supplied screwdriver to install the new Teflon Reference Junction (Cat. No. 002770HY).

6.9 Temperature Sensor Maintenance

Use soap or rubbing alcohol to remove grease, oil, or biological growth and rinse with water. Do not use any objects to poke the sensor or the transducer membrane will rupture.

6.10 Pressure Sensor Maintenance

1. If calcium deposits are forming in the port, squirt vinegar into the pressure sensor port with a syringe and soak overnight.
2. Soap or rubbing alcohol may be used to remove grease, oil, or biological material. Rinse with water. Do not use any objects to poke the sensor or the transducer membrane will rupture.

6.11 Other Sensor Maintenance

Refer to the sensor specific instruction sheet for more information.

Section 7 Replacement Parts and Accessories

Replacement Parts

Description	Catalog Number
110 VAC Power Adapter	013450
220 VAC Power Adapter	013460HY
110 VAC External Battery Pack w/Charger	011050
220 VAC External Battery Pack w/Charger	012480
Battery Adapter	011530HY
Battery Plug	004164HY
Cable, 5 meter	015005HY
Cable, 10 meter	015010
Cable, 15 meter	015015HY
Cable, 25 meter	015025
Cable, 30 meter	015030
Cable, 50 meter	015050HY
Cable, 75 meter	015075HY
Cable, 100 meter	015100
Cable, 150 meter	015150
Cable, 200 meter	015200
Cable Reel	013730
Carrying Case	011780
Calibration Cable	013470
Calibration Stand	013910
Hydras 3 LT Software, CD Kit	6234200
Cigarette Lighter Adapter	013210
Conductivity Standard—0.1 mS/cm, 1 L	013610HY
Conductivity Standard—1.413 mS/cm, 1 L	013620HY
Conductivity Standard—12.856 mS/cm, 1 L	013640HY
Conductivity Standard—47.6 mS/cm, 1 L	013650HY
Conductivity Standard—0.5 mS/cm, 1 L	013770HY
DS5, DS5X Bail Kit	013850HY
DS5, DS5X Flow Cell	014120
DS5, DS5X Pipe Kit	013540
DS5, DS5X Basic Maintenance Kit	014680HY
DS5, DS5X Storage Cup (Large)	003608
DS5, DS5X Storage Cup Cap (Large)	003609HY
Clark Cell Dissolved Oxygen Maintenance Kit	013430HY
pH Maintenance Kit	013410HY
DS5, DS5X Weighted Sensor Guard (Large)	014110HY
D.O. Electrolyte, 59 mL	000537HY
D.O. Membrane Pack	002589HY
D.O. Membrane O-ring	000498HY
External Power Adapter Cable	013170HY
Macintosh Adapter Cable	013740
MS5 Bail Kit	013950HY

Replacement Parts

Description	Catalog Number
MS5 Flow Cell	013520HY
MS5 Flow Cell (for use with turbidity sensor)	014610
MS5 Basic Maintenance Kit	013280
MS5 Weighted Sensor Guard, black (extended)	013760
MS5 Weighted Sensor Guard, black (standard)	013330
MS5 Weighted Sensor Guard, white (extended)	014910
MS5 Weighted Sensor Guard, white (standard)	014920
MS5 Mooring Fixture	013530
MS5 Pipe Kit	013550
MS5 Storage Cup Cap O-ring	002811
MS5 Storage Cup	003306
MS5 Storage Cup (extended)	003395HY
MS5 Weighted Sensor Guard	014130
Modem Adapter	012650
pH Reference Electrolyte, 100 mL	005308HY
Potassium Chloride Pellets (99% KCl), 20 pellets	005376HY
Profiler Data Analysis Software	013350
Retaining Band	005363
SDI-12 and RS485 Adapter Cable	013510
SDI-12 and RS232 Adapter Cable	013790
Small Teflon Junction	002770HY
Thumbscrew for Battery Plug	003301

Section 8 How to Order

U.S.A. Customers

By Telephone:

6:30 a.m. to 5:00 p.m. MST
Monday through Friday
(800) 949-3766

By Fax:

(970)461-3921

By Mail:

Hach Environmental
P.O. Box 389
Loveland, Colorado 80539-0389 U.S.A.

Ordering information by e-mail: sales@hachenvironmental.com

Ordering Information Required

- Account number (if available)
- Your name and phone number
- Purchase order number
- Brief description or model number
- Billing address
- Shipping address
- Catalog number
- Quantity

International Customers

Hach Environmental maintains a worldwide network of dealers and distributors. To locate the representative nearest you, send an e-mail to: sales@hachenvironmental.com or contact:

Hach Environmental; Loveland, Colorado, U.S.A.

Telephone: (970) 669-3050; Fax: (970) 669-2932

Technical and Customer Service (U.S.A. only)

Hach Environmental Technical and Customer Service Department personnel are eager to answer questions about our products and their use.

Call 1 (800) 949-3766 or e-mail techsupport@hachenvironmental.com

Section 9 Repair Service

Authorization must be obtained from Hach Company before sending any items for repair. Please contact the Hach Service Center serving your location.

In the United States and Outside Europe:

Hach Company
Hach Environmental Product Repair
North Dock
5600 Lindbergh Drive
Loveland, CO 80539-0389
Telephone: (800) 227-4224 ext 2080
Fax: (970) 461-3924

In Europe:

OTT Messtechnik GMBH & Co. KG
Ludwigstrasse 16
87437 Kempten
Germany
Telephone: +49/(0)831/5617-0
Fax: +49/(0)831/5617-209

Section 10 Limited Warranty

Hach Company warrants the Hydrolab Series 5 Sondes to the original purchaser against any defects that are due to faulty material or workmanship for a period of two years from date of shipment unless otherwise noted.

In the event that a defect is discovered during the warranty period, Hach Company agrees that, at its option, it will repair or replace the defective product or refund the purchase price excluding original shipping and handling charges. Any product repaired or replaced under this warranty will be warranted only for the remainder of the original product warranty period.

This warranty does not apply to consumable products such as chemical reagents; or consumable components of a product, such as, but not limited to, lamps and tubing.

Contact Hach Company or your distributor to initiate warranty support. Products may not be returned without authorization from Hach Company.

Limitations

This warranty does not cover:

- Damage caused by acts of God, natural disaster, labor unrest, acts of war (declared or undeclared), terrorism, civil strife or acts of any governmental jurisdiction
- Damage caused by misuse, neglect, accident or improper application or installation
- Damage caused by any repair or attempted repair not authorized by Hach Company
- Any product not used in accordance with the instructions furnished by Hach Company
- Freight charges to return merchandise to Hach Company
- Freight charges on expedited or express shipment of warranted parts or product
- Travel fees associated with on-site warranty repair

This warranty contains the sole express warranty made by Hach Company in connection with its products. All implied warranties, including without limitation, the warranties of merchantability and fitness for a particular purpose, are expressly disclaimed.

Some states within the United States do not allow the disclaimer of implied warranties and if this is true in your state the above limitation may not apply to you. This warranty gives you specific rights, and you may also have other rights that vary from state to state.

This warranty constitutes the final, complete, and exclusive statement of warranty terms and no person is authorized to make any other warranties or representations on behalf of Hach Company.

Limitation of Remedies

The remedies of repair, replacement or refund of purchase price as stated above are the exclusive remedies for the breach of this warranty. On the basis of strict liability or under any other legal theory, in no event shall Hach Company be liable for any incidental or consequential damages of any kind for breach of warranty or negligence.

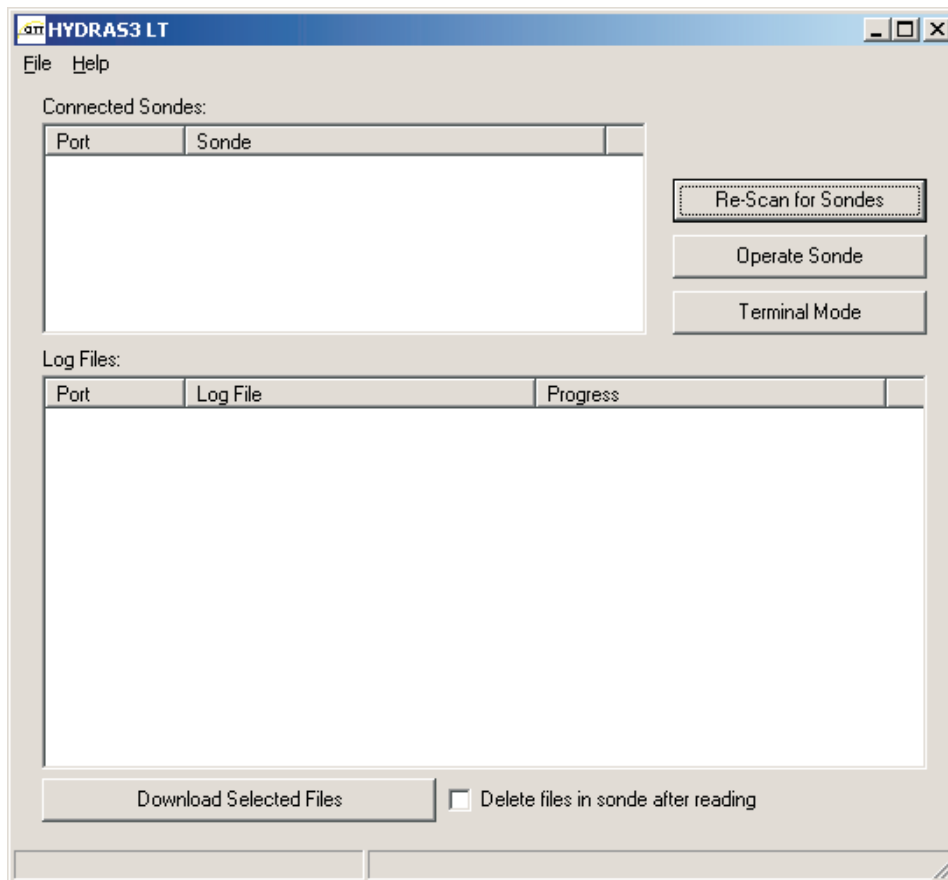
Troubleshooting Communications

If the first screen does not appear, after booting up the communications software and connecting the multiprobe to the computer, please check the following items:

Troubleshooting Hydras 3LT

If Hydras 3LT does not automatically detect the Sonde when launched:

Press the **RE-SCAN FOR SONDES** button.

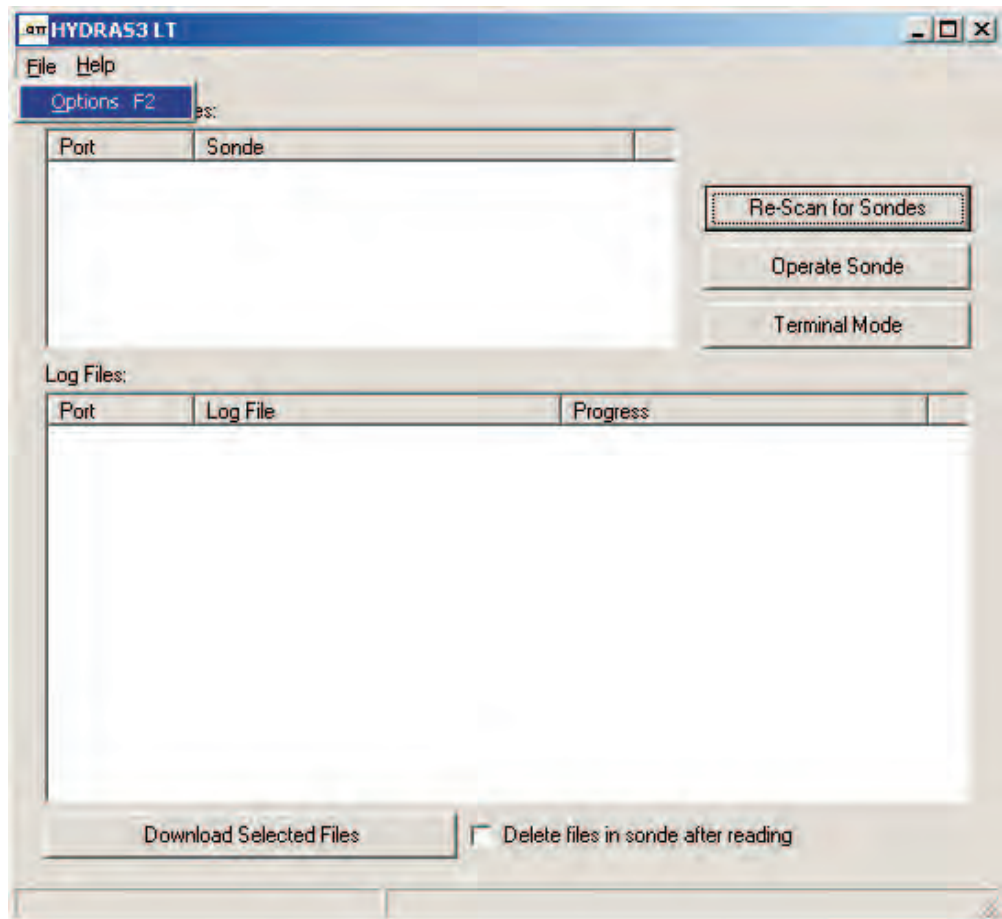


If communication is still not established after several attempts, try the following:

1. Verify that the instrument is powered on and functioning.
2. Check power cables and connections. Verify that your PC and multiprobe are properly connected to the wall outlet or external battery if used.
3. Verify that the input voltage to the multiprobe is between 7V and 18V.
4. If your multiprobe is equipped with an internal battery pack, check the batteries' polarity and voltages.

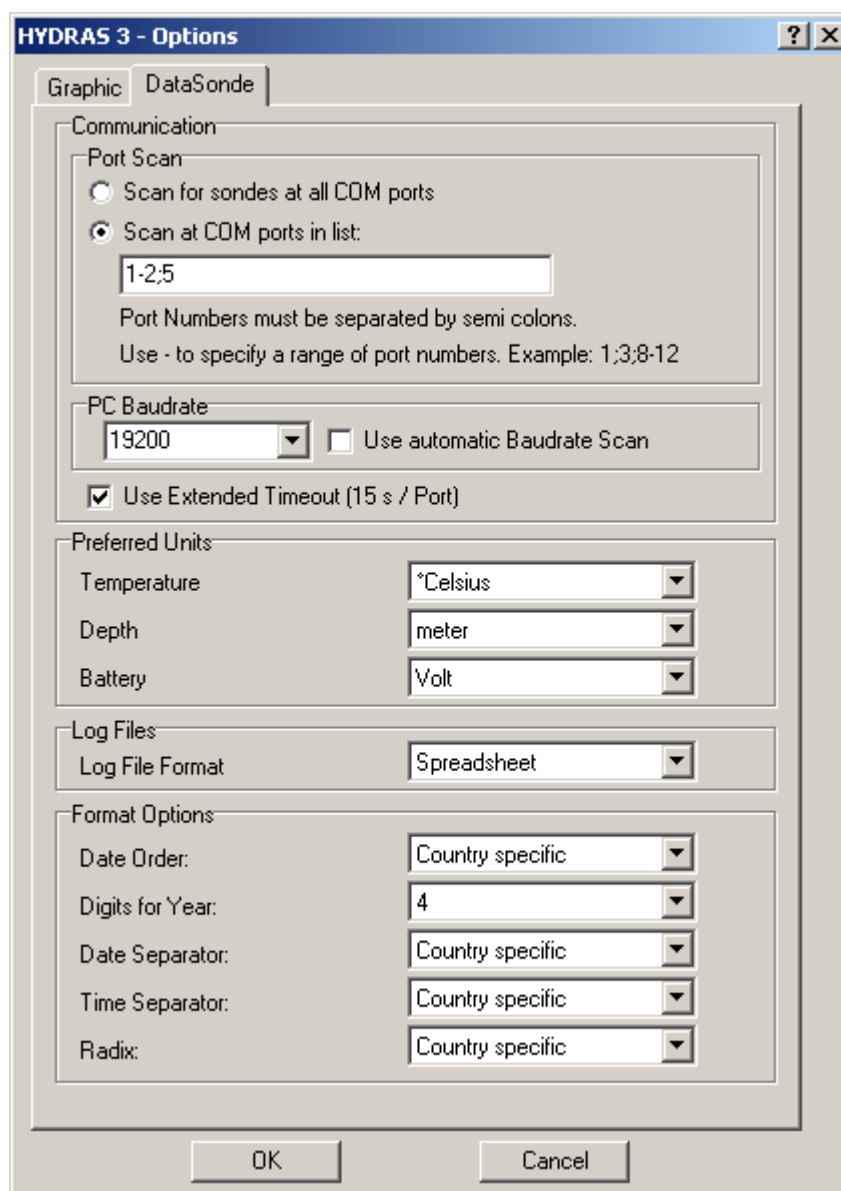
Verify the Hydras 3 LT Communication Settings.

1. Select File>Options from the Hydras 3 LT Connection Screen.



2. If the Sondes/PC baud rate and COM port are known, disable the COM Port and baud rate auto scans and set Hydras3LT to use the known values.

3. In addition, the connection timeout may be extended from 10 to 15 seconds, which will allow time for additional retries.



Troubleshooting using Terminal Mode

Check the PC and terminal emulation or communication software:

- Start the communications software before connecting the instrument.
- Verify that the PC is on and that communication software is running.
- Verify that the correct communication port was selected (COM 1, 2, 3, 4).
- Verify that the terminal was set to ANSI terminal emulation, and that the correct baud rate (19200), eight bits, no parity, and one stop bit (19200, 8, N, 1) was selected.
- If using a 100 meter or longer cable with the Surveyor, make sure the terminal baud rate is set to 9600 and the Sonde baud rate is 9600.

Check the power cables and connections:

- Verify that the PC and multiprobe are properly connected to the wall power outlet or external battery is used.
- Verify that the input voltage to the multiprobe is between 10 and 15 volts.
- Verify that the battery pack is installed correctly, if applicable. Check the battery polarity and voltages.

Check the internal components:

- Make sure all internal connections are securely seated.
- Check for the presence of water in the unit. If damp or wet, dry out thoroughly with a lint-free cloth or towel or let it sit out opened in a dry room overnight. Determine where the leak occurred and repair appropriately. Notify Technical Support for help on preventing further leaks.

If these checks do not reveal the problem, try to substitute other instruments, cables, and terminals to determine the failing component.

Troubleshooting Sensor Issues

The following list is not an extensive account of the problems encountered. If the following solutions do not reveal the problem, try to substitute other sensors to determine the failing component.

Table 1 Sensor Troubleshooting

Problem	Solution
D.O. readings are too low to calibrate and/or pH and/or Redox are very high or very low	Check the value of the sample solution
	Ensure the sensors are properly maintained.
D.O. readings seem wrong	Ensure the D.O. sensor has been properly maintained and calibrated.
Conductivity, Temperature, and/or Depth readings seem wrong	Ensure the sensors are properly maintained and calibrated.
	Ensure the readings displayed are accurate (e.g., for Depth: meters, feet, or psi).

Table 2 Multiprobe Software Symbols

Symbol	Description
#	Data Out of Sensor Range
?	User Service Required or Data Outside Calibrated Range but Still within Sensor Range
*	Parameter is Not Calibrated
~	Temperature Compensation Error
@	Non Temperature Parameter Compensation Error

Appendix B External Communications

B.1 SDI-12 Interface

SDI-12 is an industry-originated, serial digital interface bus designed to allow an operator to connect a wide variety of sensors (meteorological, hydrological, water quality, etc.) to a single SDI-12 datalogger with a single cable bus.

The multiprobe is compatible with SDI-12 V1.2. A copy of the specification can be found at www.sdi-12.org. The optional SDI-12 Interface Adapter Cable is required to operate the multiprobe with an SDI-12 Datalogger.

Note: All three wires (one ground) must be connected for correct SDI-12 operation.

A label on the SDI-12 Interface Adapter Cable shows the pinout in [Figure 19](#).

1. Connect the data cable to the SDI-12 Interface Adapter Cable connector.
2. Disconnect power from the multiprobe.
3. Connect the bare wires at the end of the SDI-12 Interface Adapter Cable to the appropriate connections on the SDI-12 datalogger. Follow the label on the SDI-12 Interface Adapter.

Figure 19 SDI-12 Cable

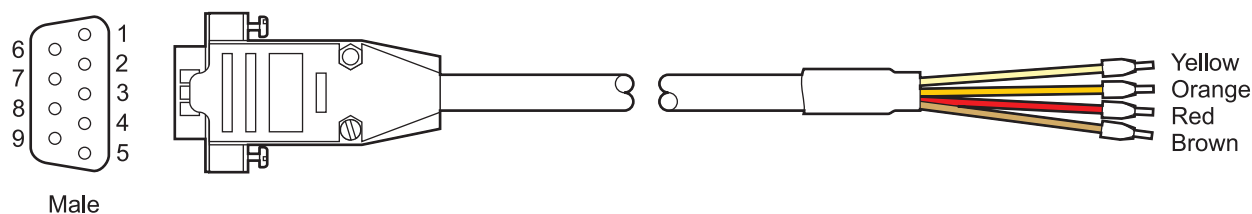


Table 3 SDI-12 Pinouts

Pin Number	Wire Color ¹	SDI-12 Function
4	Brown	+12 VDC
5	Red	Ground
8	Orange	SDI-12 Data
9	Yellow	SDI-12 Return

¹ Wire color is valid only for this cable (Cat. No 007139). Use of other cables or cable modifications may result in instrument damage.

Consult the SDI-12 datalogger manual for information on how to connect the SDI-12 Interface Adapter.

Note: SDI-12 parameters can be setup through Hydras 3 LT.

Table 4 is a summary of the SDI-12 user commands supported by the multiprobe. For more details on correct use, consult the SDI-12 V1.2 specification.

Table 4 SDI-12 Commands

Command ¹	Response	Description
a!	a<crLf>	Address Acknowledge
al!	aXXHydrolab YYYYYYZZZZserialnumber<crLf>	Identify XX: SDI-12 Support Version YYYYYY: Instrument ID ZZZZ: Software Version
aAb!	b<crLf>	Change address from a to b
aM!	addn<crLf>	Measure n values in ddd seconds
aDx!	aSvalueSvalue...<crLf>	Report Data
aRx!	aSvalueSvalue...<crLf>	Report Continuous Data
aC!	addnn<crLf>	Concurrent Measure: nn values in ddd seconds
aXC!	aXC<crLf>	Initiate a cleaning cycle in units equipped with a wiper
aX1!	aX1<crLf>	Enable Continuous Mode
aX0!	aX0<crLf>	Disable Continuous Mode
aXSS1!	aXSS1<crLf>	Circulator On
aXSS0!	aXSS0<crLf>	Circulator Off

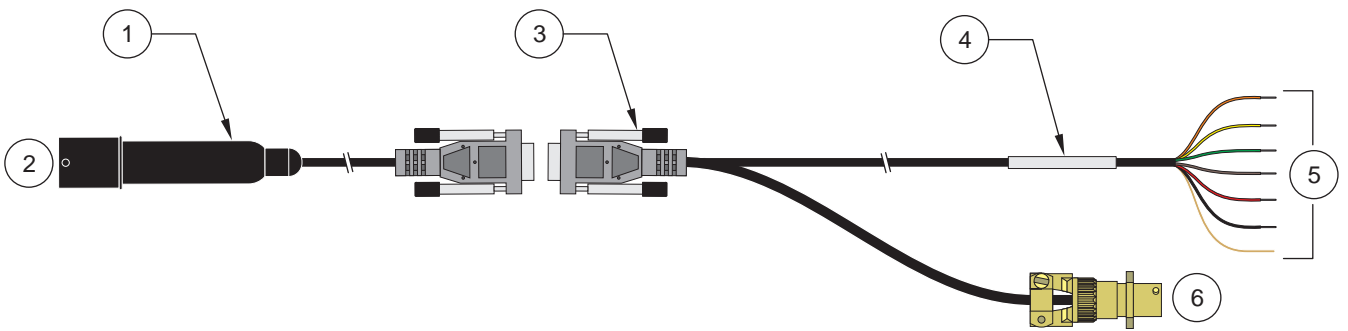
¹ The 'a' used in the SDI-12 commands is the SDI-12 address. The Transmitter's factory default SDI-12 address is '0'.

B.2 Connection to an External Device

The Series 5 Multiprobe can communicate with an external device using an RS232, RS485, or SDI-12 interface. The RS232 interface is always available. The Series 5 Multiprobe must be programmed for communication via an RS485 or SDI-12 interface.

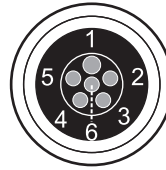
Two cables are available for external communication: a 6-pin marine to DB-9 cable (Cat. No. 015xxx), and a DB-9 to external device cable (Cat. No. 013510) for SDI-12 or RS485 interfaces (Figure 20). Wiring diagrams for these cables are shown in Figure 22 and Figure 23. Wiring for the 6-pin Sonde connector is shown in Figure 21. Wiring to the external device is detailed in Table 5.

Figure 20 Communication Cables for the DS5, DS5X, and MS5 Water Quality Sondes



1. Cable, 6-pin marine to DB-9 (Cat. No. 015XXX)	4. Label, wire connections
2. Connection to DS5, DS5X or MS5	5. Connections to external device
3. Cable for SDI-12/RS485 (Cat. No. 013510)	6. Connection to power

Figure 21 Wiring for 6-Pin Marine Connector on Multiprobe



Male

1. External Power	3. RS232 TXD	5. RS485 + or SDI-12 DATA
2. Ground	4. RS232 RXD	6. RS485 - or SDI-12 RETURN

Figure 22 Wiring Diagram for Cable 015xxx, 6-Pin Marine to DB-9

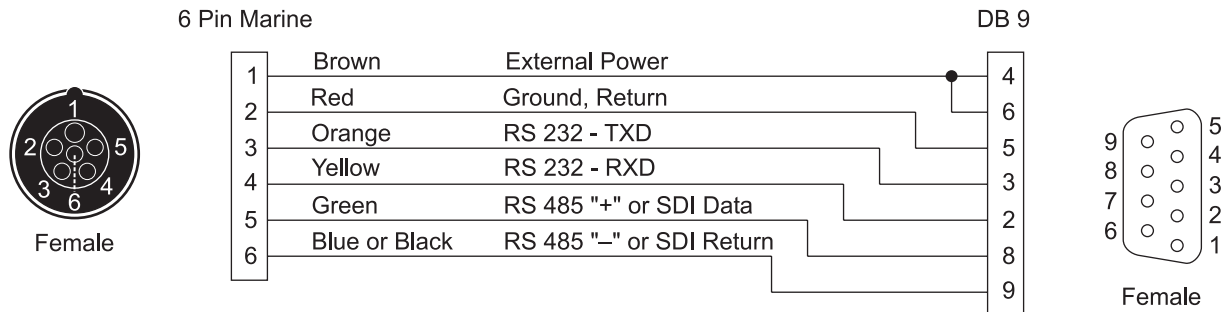


Figure 23 Wiring Diagram for Cable 013510, DB-9 to External Data Device

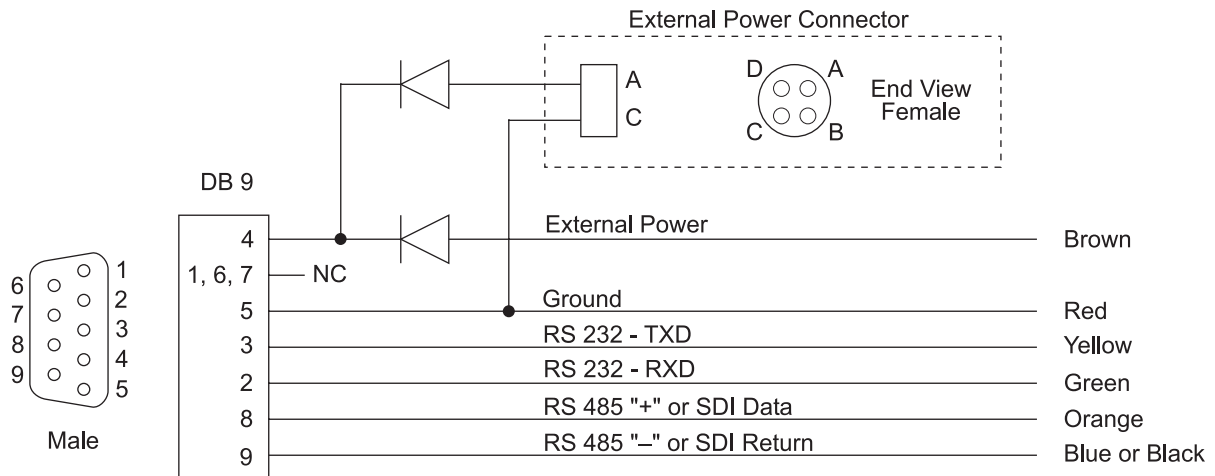


Table 5 Wiring Connections for External Device (Cable 013510)

Wire Color	RS232	RS485	SDI-12
Brown	+12VCD IN	+12VDC IN	+12VCD IN
Red/Shield	Ground	Ground	Ground
Green	RS232 RX	—	—
Yellow	RS232 TX	—	—
Orange	—	RS485 +	SDI DATA
Blue or Black	—	RS485 -	SDI RETURN

B.3 RS485 Interface

Series 5 Multiprobes are compatible with RS485 interfaces. RS485 is a standard that specifies a particular method to transmit and receive digital signals. This standard is maintained by the Electronic Industries Association in a document titled "Standard for Electrical Characteristics of Generators and Receivers for Use in Balanced Digital Multipoint Systems."

RS485 involves sending an inverted or out-of-phase copy of the signal simultaneously on a second wire. This is called a balanced transmission. Any outside electrical noise adds coherently to both signal copies. The receiver electrically subtracts the two signals to reproduce the original signal. The advantage in the subtraction is that only the intended signal gets reproduced since they are out-of-phase. The in-phase noise on the two wires are also subtracted from each other to produce a net zero noise component in the reproduced signal. This noise immunity allows the RS485 interface to transmit digital signals at faster rates over longer distances than the RS232/SDI-12 interface. The RS232/SDI-12 interface does not use balanced transmission and is therefore susceptible to noise interference which limits the transmission distance and speed.

Connections

RS485 can use two wires to both transmit and receive data. A common software protocol must be shared between devices to prevent data collisions on the wires. RS485 also allows for multiple transmitters and receivers to be easily connected together.

Be sure to connect the signal grounds of all devices on the network together. The connection can be made using a conductor in the transmission cable or each device can be connected to a good earth ground. This connection keeps the common mode voltage (the voltage which the signal must overcome to be reproduced) low. The network devices may operate without the signal ground connection, but may not be reliable.

Some RS485 applications require impedance termination because of fast data rates or long cables. The most popular termination involves installing a ½ watt resistor across the receiver at each end of the network. See the RS485 interface user manual for termination requirements on the PC being used.

Alternatively, the preferred network may be AC terminated by placing a 0.01 µF capacitor in series with the terminating resistor. The capacitor appears as a short circuit during signal transitions but appears as an open circuit to any DC loop current. This will reduce the power supply current required to operate the network and still provide the proper terminating impedance.

Do not add a terminating resistor to every receiver in the network. For networks with more than about four nodes, the transmitters will be unable to drive the cable. Only terminate both ends of the main cable.

B.4 Modbus Interface

The multiprobe is configured to respond to Modbus function 3 (Read Holding Registers) in RTU mode through the RS232 or RS485 communications port at 19200 baud, 8 data bits, Even Parity, and 1 stop bit (19200:8:E:1).

All data values are returned in IEEE Floating Point Format (4 bytes). Each data value is returned in two 16 bit words with the low word being transmitted first. Within each word, the high byte is transmitted first. Each byte is transmitted Most Significant Bit first. For example, the floating point value 1.56 = 0x3FC7AE14 would be transmitted as 0xAE 0x14 0x3F 0xC7.

All available data parameters are stored in Holding Registers within the multiprobe, which start counting at 40001. They are addressed in the Modbus message structure with addresses starting at 0. Modbus function 03 is used to request one or more holding register values from the multiprobe. Each Holding Register is 16 bits (2 bytes) in size, therefore two Holding Registers (4 bytes) are required to represent a single floating point value. Only one slave device can be addressed in a single query. The query structure is detailed in [Table 6](#). A complete register list can be found at www.hachenvironmental.com.

Table 6 Function 03 Query Structure

Byte	Value	Description
1	1–247	Slave device address
2	3	Function code
3	0–255	Starting address, high byte
4	0–255	Starting address, low byte
5	0–255	Number of registers, high byte
6	0–255	Number of registers, low byte
7	0–255	CRC, high byte
8	0–255	CRC, low byte

After processing the query, the multiprobe will return the 16 bit Holding Register values that were requested. The Holding registers will be transmitted as High Byte first, followed by the Low Byte. The Modbus response starts with the multiprobe address and the function code 03. The next byte is the number of data bytes that follow. This value is two times the number of registers returned. The two byte CRC is appended at the end.

Example: The multiprobe stores pH information at holding registers 40007 and 40008. These registers are addressed as 0x0006 and 0x0007. The following sequence of bytes request pH from a multiprobe with slave address 1.

pH Query Example:

Byte 1 ¹	Byte 2 ²	Byte 3 ³	Byte 4 ³	Byte 5 ⁴	Byte 6 ⁴	Byte 7 ⁵	Byte 8 ⁵
0x01	0x03	0x00	0x06	0x00	0x02	0x24	0x0A

¹ Slave Address

² Command 3—Read Holding Register

³ Address of the first Holding Register to read (0x0006)

⁴ Number of Holding Registers to Read (2 registers—4 bytes)

⁵ CRC

Response:

Byte 1 ¹	Byte 2 ²	Byte 3 ³	Byte 4 ⁴	Byte 5 ⁴	Byte 6 ⁴	Byte 7 ⁴	Byte 8 ⁵	Byte 9 ⁵
0x01	0x03	0x04	0xA8	0xC9	0x41	0x06	0xBA	0x3F

¹ Slave Address

² Command 3—Read Holding Register

³ Number of Data Bytes (4 bytes—2 registers)

⁴ pH

⁵ CRC

Result: The data is sent Low Word First, High Byte First, therefore the IEEE Floating Point Formatted value representing the pH is: 0x4106A8C9 = 8.416 Units.

B.5 Using a Modem with Multiprobes

Field Modem

All multiprobes require a modem adapter to enable communications with a commercial telephone modem. The modem adapter provides the necessary handshaking and connections to allow a modem to properly answer the incoming call and power down the multiprobe when the call is terminated. The Modem Adapter has a connector (labeled modem) that connects to the RS232 connection of the modem. The other connector (labeled multiprobe) on the Modem Adapter connects to the multiprobe using a Interface cable and Underwater cable, or a Calibration cable. A 25 to 9 pin adapter is also required for the cables.

The Modem Adapter does not require a power supply, however, the multiprobe and the modem will require power. Usually, commercial modems are supplied with a wall-cube power supply that converts ac mains voltage to 9–12 volts DC. Most modem can use the multiprobe power supply by making a cable with the corrector connector for the modem power input.

The modem, Modem Adapter, power supply, and associate cabling are not water-proof, and should be installed in a water-tight enclosure. If AC power is used, then a GFI (ground fault interrupt) device should be installed in the ac wiring to prevent electrocution. Program the modem as follows:

Table 7 Field Modem Commands¹

Command	Function
AT&C1	Enable carrier detection
AT&D3	Enable DTR detection
AT&K4	Enable XON/XOFF handshaking
AT&Q0	No error correction or buffering
AT&S0	Force continuous DSR
AT%C0	Disable data compression
ATS0=1	Answer on first ring
AT&W0	Save current settings

¹ The modem will automatically use this setup every time it is powered on.

Office Modem Installation

The office modem is connected to the computer serial port using a standard RS232 connection. Program the modem as follows:

Table 8 Office Modem Commands¹

Command	Function
ATW1	Report connection speed & protocol
AT&C1	Enable carrier detection
AT&K4	Enable XON/XOFF handshaking
AT&Q0	No error correction or buffering
AT%C0	Disable data compression
AT&W0	Save current settings

¹ The modem will automatically use this setup every time it is powered on.

The computer will need a terminal emulation program to communicate with the remote multiprobe. Setup the program to provide ANSI terminal emulation, 19200 baud, no parity, 8 data bits, and 1 stop bit for Series 5 Multiprobes. Setup the software to provide a direct connection to the COM port connected to the modem.

Operating the Modem

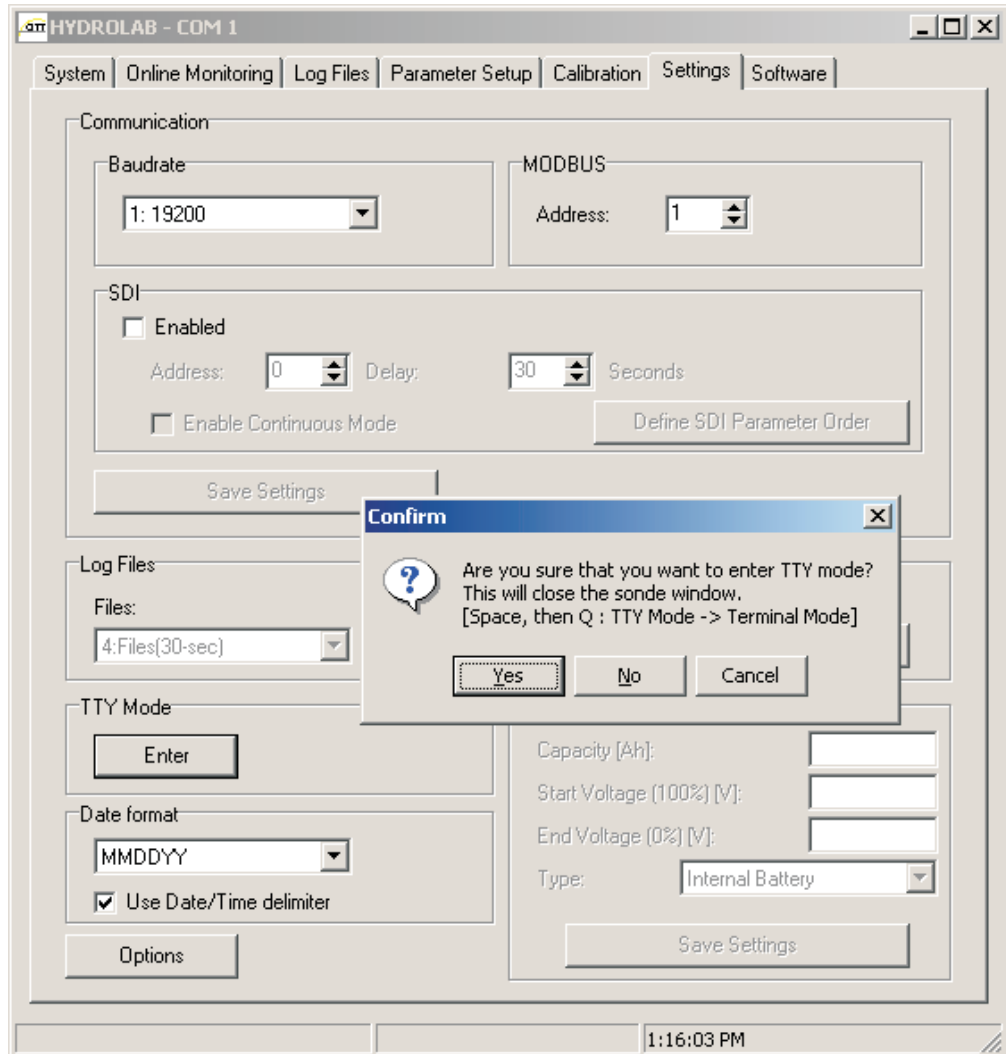
Check if the modem is communicating with PC by typing **AT** and pressing **ENTER**. The modem should respond with **OK**. To access a remote site from the office, type **ATD** followed by the phone number, for example, **ATD15122558841**. Add the proper prefixes to the phone number such as 9 (for PBX office systems) or 1 (for long distance). Press **ENTER**. The modem should start dialing the number and negotiating the connection. Series 5 Multiprobes may require as long as 15 seconds to show the startup screen. If the startup screen is not displayed, send a Break by typing **ALT-B**. Telephone noise and delay may prevent the Series 5 Multiprobe from properly determining the presence of an ANSI terminal. You will not be able to access a Series 5 Multiprobe if logging event is currently active. This can be avoided by setting the interval to no less than 2 minutes to allow enough time to call the modem between logging events (a logging event occurring during a call will not cause a problem).

B.6 TTY Mode

The sonde is equipped with a TTY Communication Mode, which enables the Sonde to send an ASCII string of characters, representing selected parameter values, once per second. Parameters and Parameter Order may be selected using the "Define SDI Parameter Order" button in the SDI section of the Settings Tab.

To enter TTY Mode:

1. Press **ENTER** in the TTY Mode section of the Settings Tab.
2. Press **YES** to verify the entry in mode.



Once the Sonde has been placed in TTY mode, it will no longer communicate with Hydras3LT except in terminal mode. The Sonde will retain its current baud rate. Any ANSI terminal emulator may be used to communicate with the Sonde at 8 data bits, No Parity, and 1 stop bit.

B.6.1 TTY Menu and Commands

The TTY menu is accessed by first pressing the spacebar (or sending an ASCII space character). The multiprobe will finish any line in progress and then start a new line (by sending <cr><lf>) followed by the menu:

```
<cr><lf>HM?:<sp>
```

The multiprobe will echo the user entry if it is listed in the menu, otherwise an ASCII BEL character is sent. An ASCII escape character will abort the menu after displaying a cancel message.

Responding with a ? will produce a verbose version of the menu:

```
<cr><lf>Main Menu<cr><lf>
(H)eader<cr><lf>
(M)easure<cr><lf>
(Q)uit TTY Mode<cr><lf>
Please enter your choice:<sp>
```

A. (H)header

Responding with an H will show a header identifying the data fields with name and units. In addition, the instrument ID is displayed:

```
HM?:<sp>H<cr><lf>
<cr><lf>Instrument Id<cr><lf>
<cr><lf><sp><sp>Time<sp><sp><sp>Temp<sp><sp>lbatt<cr><lf>
HHMMSS<sp><sp><sp><sp><sp>°C<sp><sp>Volts<cr><lf>
```

The first line is free-field text up to 20 characters in length. The next line is skipped and the data names are printed. The names are right-justified (with leading spaces inserted) to produce a constant width field. Most fields are 6 characters wide, however fields can also be 5, 7, or 8 characters wide. The name fields are always separated with a space. Any name may appear in any field depending on how the user configured the data display in ANSI mode.

The next line shows the corresponding units for the data fields. The units are right-justified text (with leading spaces inserted) to produce a constant-width field equal to the name field. The name fields are always separated with a space.

B. (M)measure

Responding with an M will force the multiprobe to send one line of data without waiting for the next data display interval. This is useful for synchronizing data acquisition software with the multiprobe data output. The data values are right-justified to fill a constant-width field of 5, 6, 7, or 8 characters.

```
HM?:<sp>M<cr><lf>
231302<sp><sp>24.59<sp><sp><sp>12.0<cr><lf>
```

Data values may also be appended with a special character (*, ~, @, #, or ?). Data values without an appended character will always have a space separator, however, the appended character may be the only separator between values; a space separator is not guaranteed.

Data values that are too large to fit in the constant-width field, are modified so that the numeric digits are displayed as # (###.## for example). The sign and decimal point are preserved.

C. (Q)uit

Responding with a **Q** or **q** will reset the multiprobe to full terminal mode and can then be connected to Hydras 3 LT.

B.6.2 Data Display

If the TTY menu is not used, a line of data is periodically displayed on the next available line. If the screen is full, the lines are scrolled. All data lines are terminated with <cr><lf> and have the same formatting as the (M)easeure command described above.

Appendix C Using HyperTerminal

C.1 HyperTerminal Setup

1. After starting Windows, click on the Start button.
2. Select Programs>Accessories>Communications>Hyperterminal.
3. Enter a name and choose an icon for the application and click **OK**.
4. Select the COM port and click **OK**. Set the communication in a 19200/8/N/Xon-Xoff format.
5. Configure HyperTerminal so the functions, arrows, and **Ctrl** keys act as terminal keys, not window keys. Select the ANSI terminal emulation. File>Properties>Settings.
6. Use [Table 9](#) to communicate with or recover information from the multiprobe.

Table 9 HyperTerminal Commands

Follow the Path:	To:
Help: Help Topics: Index: HyperTerminal	Displays the on-line help utility.
File: Properties: Phone number: Configure: Maximum speed	Access and select the modem transfer speed (e.g. 19200 bps)
File: Properties: Phone number: Configure: Connection	Access and select the connection settings (e.g. N, 8, 1)
Transfer: Capture Text	Enable a capture file, to log the data currently received to a disk or to a hard drive. You will be prompted for a file name and a path.
File: Capture to printer	Turn the printer on.
Transfer: Send file	Upload a file and choose the transfer protocol (e.g. Xmodem). You will be prompted for a file name and a path.
Transfer: Receive File	Download a file and choose the transfer protocol (e.g. Xmodem). You will be prompted for a file name and a path.
File: Open	To view a file or find a saved file in the HyperTerminal folder.

Appendix D Glossary & Abbreviations

Ammonia (NH₃)—A colorless gaseous alkaline compound which is soluble in water. It has a characteristic pungent odor, and is used as a fertilizer. In water and soil, ammonia is present primarily as NH₄⁺ ions and is readily assimilated by plants during nutrition.

Ammonium (NH₄⁺)—Ammonium is a form of ammonia by the addition of a hydrogen ion (H⁺) to an ammonia molecule (NH₃). Ammonia is converted to ammonium as the pH of a solution drops. Ammonium is less harmful to aquatic life than ammonia. Below a pH of 7.3, more than 99% of the total ammonia is present as ammonium.

Assembly—A unit containing the component parts of a mechanism, machine, or similar device. Probe Assembly: The unit containing the component parts of a sensor (e.g. D.O.:component consisting of the D.O. sensor which is made up of 2 electrodes the cathode and the anode).

Chloride (Cl⁻)—A common anion, present in both fresh and sea water. It is essentially non-toxic, and is present in all living cells.

Conductivity—Conductivity is inversely related to the resistance of a solution. Conductivity is the ratio of the electric current density to the electric field in a material, also known as electrical conductivity. In limnology, conductivity is a measure of the ability of water to pass an electrical current. Compensation of this measurement to 25 °C constitutes specific conductance. This parameter indicates the amount of dissolved substances (salts). Salts and their concentration dictate osmoregulatory (salt-balancing) functions in plants and animals. The ionic strength of water also regulates the toxicity of many substances. (See: Specific conductance)

Data collection platform (or DCP)—Hardware system and system software used with a computer program to collect data at one or more locations.

Depth—The vertical distance between the water surface and another level (for a multiprobe: 0–10, 0–25, 0–100, or 0–200 meters). (See: Vented depth)

Derating—The reduction of the rating of a device to improve reliability or to predict operation at higher or lower ambient temperatures.

Dissolved oxygen (or D.O.)—A measure of the amount of oxygen present in water and available for respiration. The concentration of D.O. is controlled by many factors including: consumption by aerobic (requiring D.O.) organisms (bacteria, fish, amphibians, and invertebrates); consumption by plants (algae, vascular plants, particularly during dark hours); and water temperature, water flow, and depth

Drift— The long-term lack of repeatability caused by fouling of the sensor, shifts in the calibration of the system, or slowly failing sensors.

Dump—To copy the contents of all or part of a storage, usually from an internal storage device to an external storage device.

Eh—(See: Redox potential)

Electrode—An electric conductor which either measures the potential of a solution (pH, reference, redox, and ammonium electrodes) or forces electric current into or out of a solution (D.O. and conductivity electrodes).

Emery cloth—An abrasive cloth or paper with an adherent layer of emery powder; used to polish and clean metal. (No. 400 or finer is recommended.)

Hysteresis error—The maximum separation due to hysteresis between upscale-and downscale-going indications of a measured value. A difference in parameter readings which occurs due to a variation in the conditions under which the sensor approached the readings. (See: Response time)

Isopotential point—The point at which the ion activity is the same on both sides of a sensor membrane. At the isopotential points, there is a zero potential across the membrane. The observed potential of the sensor may not be zero, due to the differences in reference electrodes.

Milliohm ($m\Omega$)—Unit of resistance (not conductivity or conductance.)

MilliSiemens (mS) = millimho (m)—Units of electrical conductance.

Millimho (m)—(See: MilliSiemens)

Molar concentration—Molar solution: Aqueous solution that contains one mole (unit = gram-molecular weight) of solute in one liter of water. For example: KCl (potassium chloride) molar concentration.

Multiprobe—The combination of several sensors, electrodes, or probe assemblies into a complete, stand-alone piece of equipment which simultaneously measures several parameters for profiling, spot-checking, or logging readings and data. A multiprobe is a multi-parameter instrument.

Nitrate (NO_3^-)—Nitrate is the most oxidized form of nitrogen, and is the primary form of biologically available nitrogen present in aerobic environments. Nitrate is a less toxic form of nitrogen than ammonia, and is readily assimilated by plants and bacteria.

Oxidation reduction potential (or ORP)—(See: Redox potential)

Parameter—A quantity which is constant under a given set of conditions, but may be different under other conditions.

pH—Describes the hydrogen-ion activity of a system: pH 0–7: acid solution, pH 7: neutral, pH 7–14: alkaline (or basic) solution. The "p" in pH stands for power (puissance) of the hydrogen ion (H^+) activity. pH is a major factor affecting the availability of nutrients to plants and animals. It controls in part the concentration of many biochemically active substances dissolved in water, and it affects the efficiency of hemoglobin in the blood of vertebrates (e.g. fish) and invertebrates (e.g. shrimp), as well as the toxicity of pollutants.

Probe—A small tube containing the sensing elements of electronic equipment. The probe is an essential part of the water quality monitoring system, since it obtains measurements and data which can be stored, analyzed, and eventually transferred to a computer.

Probe assembly— (See: Assembly)

Profiling—Electrical exploration wherein the transmitter and receiver are moved in unison across a structure to obtain a profile of mutual impedance between transmitter and receiver = lateral search. In water quality, this term is used as the contrary of unattended monitoring. An operator connects the multiprobe to a computer equipped with a communications software. Then, he lowers the multiprobe in the water and receives measurements from the instrument. The data is displayed on the computer screen. The multiprobe can be lowered to different locations along the sample area in order to study the nature of the water based on several points of reference.

Quinhydrone ($C_6H_4O_2 \cdot C_6H_4(OH)_2$)—green, water-soluble powder. Quinhydrone is used to calibrate redox sensors. The quinhydrone's redox potential is dependent on the pH of the solution.

Reading—The indication shown by an instrument.

Redox potential = Oxidation-reduction potential (or ORP) = Eh—Voltage measured at an inert electrode immersed in a reversible oxidation-reduction system; measurement of the state of oxidation of the system. The redox potential measures the tendency of electrons to "flow" either toward or away from a noble metal electrode. A substance gains electrons in a reduction reaction and loses electrons in an oxidation reaction. ORP varies from substance to substance, and oxidation-reduction reactions occur simultaneously, hence the determination of the "potential" rather than of a discrete or qualitative value. Oxidation and reduction are in a constant state of flux, continuously seeking equilibrium. Applications for ORP measurement include, but are not limited to, the following: monitoring oxidation of cyanide and chromate wastes (e.g. metal plating), bleaching pulp (e.g. paper manufacturing), manufacture of bleach (e.g. monitoring chlorination), water pollution (e.g. acid mine drainage) and monitoring ozone treatment (e.g. water disinfection). ORP data has been used to understand more about how substances in sediments affect the water quality at the bottom of lakes, reservoirs, and ponds.

Reduction—A reaction that increases the electron content of a substance.

Reference electrode—A nonpolarizable electrode that generates highly reproducible potentials; used for pH, ORP, and ammonium measurements and polarographic analyses (e.g. silver-silver chloride electrode).

Resistivity—Resistivity is the electrical resistance offered by a material to the flow of current, times the cross-sectional area of current flow and per unit length of current path. It is the reciprocal of conductivity and is also known as electrical resistivity and specific resistance. Resistance declines as ion content increases.

Response time—The time required for a system to react, by a prescribed amount, to a step change in some variable. The extent of the response must be stated, as in "to 95% of total change" or "to within 0.1 mg/l of the final reading" (example for D.O.).

Salinity—Salinity is the measure of the total quantity of dissolved salts in water. Salinity refers to the ionic strength of natural waters. Salinity and salt concentration are the only terms that can be used when referring to the relative concentration of certain salts in bays, estuaries, and oceans.

SDI-12—SDI-12 is a standard used to interface data recorders with microprocessor-based sensors. SDI-12 stands for serial-digital interface at 1200 baud. SDI-12 is intended for applications with the following requirements: battery-powered operation with minimal current drain, low system cost, use of a single data recorder with multiple sensors on one cable, and up to 200 feet of cable between a sensor and a data recorder.

Sensor—The generic name for a device that senses either the absolute value or a change in a physical quantity such as temperature, pressure, flow rate, or pH, and converts that change into a useful input signal for an information-gathering system.

Service loop—A loop in a wire or cable to reduce the load on the wire or cable.

Slope—Slope is the operation applied to the system's response once the zero has been set. Slope is a measure of the sensitivity of a sensor. Slope scales the sensor's output to the correct units. (Also see: Zero)

Specific conductance = conductivity at 25 °C—The ratio of the electric current density to the electric field in a material. The ability of a fluid to conduct electricity. Specific conductance is the inverse of electrical resistivity, corrected at 25 °C, since fluids conduct more at higher temperatures.

Spot-checking—The collection of data using readings at irregular intervals.

Temperature—A measure of heat present in water. Aside from dissolved oxygen, temperature is considered the single most important parameter. Knowledge of water temperature is essential to the measurement of dissolved oxygen, conductivity (salinity), pH, alkalinity, biological/biochemical oxygen (needed to meet the metabolic needs of aerobic - requiring D.O. - organisms) and virtually every other water quality parameter. Temperature controls metabolism (utilization of inorganic and organic matter for life processes) of aquatic animals and plants. Temperature is largely responsible for biochemical reactions and is one of the most important cues for beginning and ending of spawning, migration, and many other phenomena.

Titration—A method of analyzing the composition of a solution by adding known amounts of standardized solution until a given reaction - color change, precipitation, or conductivity change - is produced. Winkler titration (in calibration): A wet chemical method for estimating the D.O. in water.

Tolerance—Refers to the maximum difference between the true value of a parameter and the actual "operator-acceptable" reading. Usually used as a synonym for accuracy.

Total dissolved gas (TDG)—The amount of gaseous compounds dissolved in a liquid.

Total dissolved solids (TDS)—The amount of materials in a body of water that are dissolved or too small to be filtered. These solids include ions, which are important to the internal water balance in aquatic organisms. The amount of substances (calculated in Kg/l) dissolved in one liter of water. A measure primarily of alkaline earth metals and their salts dissolved or in very fine suspension. It provides information regarding the potential buffering capacity of water, water hardness, and the potential lethality of toxins. The concentration of dissolved solids affects osmoregulation (salt balancing) and is often a cue for migration and spawning. TDS concentration affects the buoyancy of fish eggs and other organisms.

Transducer—Any device or element which converts an input signal into an output signal of a different form (ex: doorbell, microphone). The depth or vented level transducer.

Turbidity—The measure of the clarity of a liquid by using colorimetric scales. It is also the expression of the optical property that causes a light to be scattered and absorbed rather than transmitted in straight lines through a sample. Turbidity is the opposite of clarity (ITM) A measure of the opacity or translucence of water. The main objective is to determine the scattering of light by particles of a body of water and report that scattering in some unit of measurement, usually nephelometric turbidity units (or NTU) based on a primary turbidity standard called formazin. Turbidity is caused by plankton (both animal and plant), clay, suspended clay, silt, etc. Although these substances impart color, color resulting from turbidity is referred to as "apparent color" and should not be confused with true color (resulting from dissolved substances). Apparent color can also result from overshadowing by vegetation or substrate (bottom material) color.

Vented depth—(ITM) The multiprobe transducer measuring depth from 0 to 10 meters. (See: Depth)

Zero—(ITM) A system's "zero" is an anchor point set either temporarily by calibration or permanently by design. This point can easily be established either electronically or by using laboratory standards. (Also see: Slope).

Abbreviations

AgCl	Silver Chloride	MS	MiniSonde
Ah	Ampere hour	mS/cm	MilliSiemens per centimeter
AWG	American wire gauge	mV	Millivolt
BDR	Basic data recorder	nm	Nanometer
BP	Battery pack; barometric pressure	PA	Probe Assembly
CC	Calibration cable	PCB	Printed circuit board
°C	Degrees Celsius (centigrade)	ppt	Part per thousand
CSV	Comma-separated value	psu	Practical salinity unit
DS	DataSonde	psiag	Pound per square inch absolute
EPA	External battery pack	psig	Pound per square inch gage
°F	Degrees Fahrenheit	RBP	Rechargeable battery pack
GFI	Ground fault interrupt (device)	RGA	Returned good authorization
IBP	Internal battery pack	SDI	Serial-digital interference
IC	Interface cable	STDREF	Standard reference electrode
K	Degrees Kelvin, or kelvin. A unit of absolute temperature.	CIRCLTR	FreshFlow™ miniature sample circulator
KCl	Potassium chloride	SVR	Surveyor
l or L	Liter	WSG	Weighted sensor guard
mmHG	Millimeter of mercury (hectoPascal and millibar also used in Europe)	4PF	4-pin female connector
mil	A unit of length, equal to 0.001 inch	4PM	4-pin male connector
...M KCl	...molar potassium chloride	6PF	6-pin female connector
µm	Micrometer	6PM	6-pin male connector
m	Millimho = milliSiemens (mS)	9PF	9-pin connector
µS/cm	MicroSiemens per centimeter = micromho per cm	9PM	9-pin male connector
m	Meter (1 meter = 3.281 ft)		

Appendix B

Protocol for Aquatic Plant Survey Collecting, Mapping, Preserving and Data Entry

Below we outline the protocol for statewide baseline sampling of aquatic macrophytes, with the primary goals of 1) comparing year-to-year data within a lake, and 2) comparing data among lakes. We describe a formal quantitative survey conducted at pre-determined sampling locations distributed evenly over the lake surface (point-intercept approach). We believe that this method, when combined with a boat survey to gather additional information on areas not sampled directly, will best characterize a lake's plant community. The chief benefit of adopting a statewide protocol is that variation in the sample set can be primarily attributed to actual differences in plant communities, instead of the confounding variables introduced by using different sampling techniques.

These guidelines are intended to work on most lakes. However, modifications may be required if a lake is uniquely shaped so that a uniform distribution of points isn't representative (long, skinny lake shape), or if obtaining rake samples is difficult due to substrate (rocky/cobble bottom).

Please note these are “baseline” recommendations. Additional monitoring activities may be warranted if the goal is to assess a specific management activity. For example, to gauge the success of chemical spot-treating stands of an exotic species in a relatively large lake, we recommend additional mapping of the beds within a season before and after treatment.

The baseline sampling described below should be conducted between early July and mid August. Although changes (such as biomass) in the plant community through this long sampling window might complicate data interpretation, in this survey we are mostly interested in species diversity and frequency, variables that should be fairly constant through the growing season. However, as described below, field workers are asked to assess rake fullness for all species and these ratings will likely vary with sample date. For many species, including Eurasian water-milfoil, plant biomass and density will probably increase as the season progresses. Narrow-leaved pondweeds begin to disappear by mid-August. Data for these species must be interpreted carefully with the sampling date in mind.

Curly-leaf pondweed (CLP) creates a special problem because it is often gone before the recommended sampling window between early July and mid-August. If you have any suspicion that CLP is present but not found when sampled, be sure to talk to APM staff to work out the best sampling scheme.

DNR personnel and groups using state money (e.g. planning, protection or aquatic invasive species grants) must follow this protocol.

I. Field Equipment

1. Required field equipment: boat, handheld GPS unit with WAAS (Wide Area Augmentation System) capability (with site locations already loaded, Garmin 76 is a commonly used model within DNR), a lake map, waterproof field data sheets, pole-mounted rake, weighted rake on a rope, depth finder, storage bags for vouchered specimens, personal flotation device.

2. Recommended equipment (helpful, but not necessary): trolling motor, underwater video camera, plant ID references, hand lens, cooler for storing samples, digital camera to document shoreline features (e.g., deadfall, dock, house) for sample points near shore that will provide a visual complement to a dot on a map, waterproof paper tags and/or Sharpie for labeling bags with vouchers and unknown plant species.

II. Point Intercept Sampling Method

1. Description

We require the following point-intercept sampling protocol. In this method, a large number of sampling sites are distributed in a grid across the lake. There are several benefits to a grid sampling design. An evenly spaced distribution of points results in a good overview of the entire lake. It is easy to replicate, and it is easy to preserve and present the spatial information. Please contact Jen Hauxwell (Jennifer.Hauxwell@dnr.state.wi.us) with lake name, county, water body identification code (WBIC), and any other depth and plant information available so that she can establish sampling points for the lake.

The size of the littoral zone and shape of the lake determines the number of points and the grid resolution. You will receive an electronic file of sampling points to upload into a GPS unit (below). Once on the lake, you will go to each site and collect plants and data as described below.

2. Uploading sampling points to the GPS unit

The following step-by-step instructions were adapted from the WIDNR Garmin GPS Tool User Manual v. 8.2.5, available to DNR employees on the intranet.

file:///C:/central/Cet_apps/CPROD/CWiDNR_Garmin/Cstandalone_garmin/CDEV_Doc/CWiDNR_Garmin_Standalone_GPS_Tool_User_Guide.pdf

This is a two step process. First you need to *_load_* the sample points you receive from Jen Hauxwell in a text file into the WIDNR Garmin GPS Tool, a computer file. Second you need to *_upload_* the points from your computer onto the GPS unit itself. For more information or troubleshooting help consult the User Manual.

Please note that GPS units vary in how many way points they can store. In the event that the number of sampling points exceeds your unit's storage capacity, simply split the text

file containing the point information into multiple files. Upload successive files of points as needed.

(For more information on Garmin GPS units, please see <http://www.garmin.com/> and navigate to consumer/outdoor/GPS mapping. Choose a unit and then click on “specifications” and, under navigation features, find the number of waypoints/icons.)

To upload points into your GPS unit from a text file (.txt) using the WIDNR Garmin GPS Tool you will need:

- **PC/laptop with WIDNR Garmin GPS Tool software.** If you do not have the software on your computer contact your administrator for installation.
- **Waypoint .txt file** in the same format as one created by the WIDNR Garmin GPS Tool. Text files received from DNR Research will be in the correct format.
- **PC Interface cable.** Comes standard with the GPS unit, or can be ordered at <http://www.garmin.com/outdoor/products.html#mapping>.
- **GPS unit with external data port.**

Step 1: SET “SIMULATING GPS” MODE

You must operate the Garmin GPS receiver in Simulating GPS mode while uploading/downloading data, so that the receiver is not trying to acquire satellite data during these activities. Check your GPS manual to determine how to do this. Instructions for the GPSMap 76 are given below.

1. Press and hold the [ON/OFF] button for two seconds to turn the GPS receiver on.
2. Several informational screens will display. Press the [PAGE] button until the first Acquiring Satellites screen appears.
3. Press the [MENU] button and select Start Simulator to see the Simulating GPS page.

Step 2: SET SERIAL DATA FORMAT

You must set the serial data format to GARMIN prior to transferring data. Failure to set the serial data format to GARMIN will cause a communication error between the WIDNR Garmin Tool and the GPS unit. Instructions for a GPSMap 76 are given below.

1. Press the [MENU] button twice, use the rocker key to select Setup, and then press [ENTER].
2. Use the rocker key to scroll left or right until the Interface tab is highlighted. Use the rocker key to scroll down to highlight the drop-down box and press [ENTER].

3. A menu will appear; select GARMIN and [ENTER]. Press [QUIT] twice to return to the main screen.

Step 3: PLUG IN THE PC INTERFACE CABLE

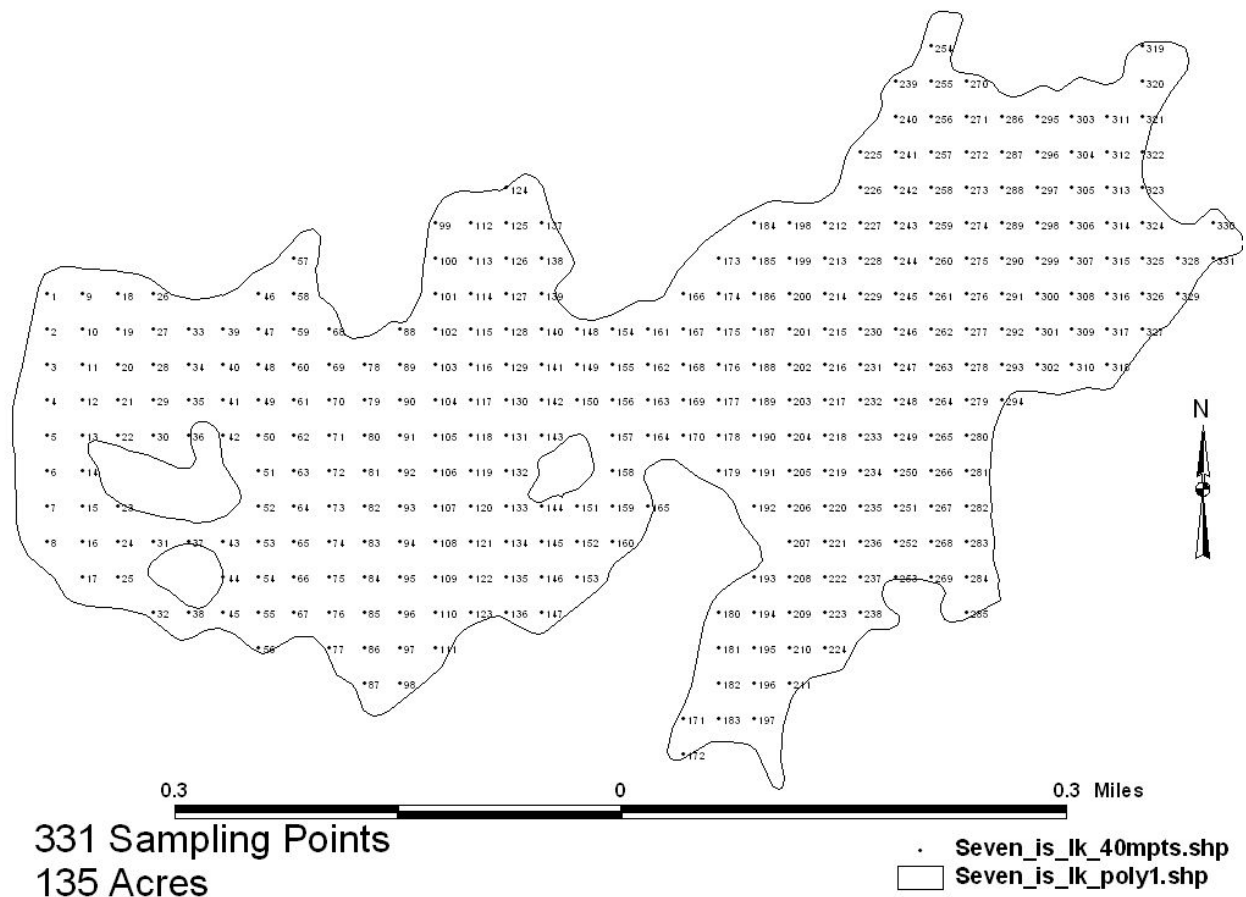
1. Plug the 9-pin serial connector into COM port #1 on your PC. If port #1 is in use, plug into the next available port, and note the port number. The WIDNR Garmin GPS Tool does not support connection through a USB port.
2. Plug the round end of the cable into the external data/auxiliary power port on the back of the GPS receiver. Check your GPS manual if you do not know where the data port is located. The GPS receiver should be on and in “simulating GPS” mode.

Step 4: LOAD WAYPOINT DATA FROM A TEXT FILE TO THE WIDNR GARMIN GPS TOOL

1. Open the WIDNR Garmin GPS Tool file on computer. Select the WIDNR Garmin GPS Tool > File > Load > Waypoints From > GPS Text File option.
2. Enter/Select the path and name of the text file to load into the Open window. The GPS data will be loaded into the WIDNR Garmin GPS Tool. If you have trouble at this point, see the next section on troubleshooting. Otherwise, go on to section 4, Waypoints.
3. Troubleshooting. If you encounter problems during loading, a pop-up window will notify the user. Click OK.
 - a. If problems are encountered, check that the COM port is set correctly: GPS > Assign Port > select correct port #.
 - b. Also check that the baud rate matches that of the GPS unit: GPS > Assign Port > Baud Rate > select correct rate. A GPSMap 76 will transfer at 9600.
 - c. Check that the Serial Data Format is set to GARMIN (outlined in Step 2).
4. Waypoints. You can now view/edit waypoints by clicking the [Advanced] button on the WIDNR Garmin GPS Tool window.

Step 5: UPLOAD WAYPOINT DATA TO THE GPS RECEIVER

1. Select the WIDNR Garmin GPS Tool > Waypoint > Upload option.
2. When complete, the number of uploaded points appears at the bottom of the Garmin GPS Tool window. A pop-up window also indicates the number of waypoints successfully uploaded. Click OK. The uploaded waypoints should now be visible on the GPS receiver's Waypoints display.
3. Below is an example of lake with waypoints.



III. Collecting and Recording Plant Data

1. The rake sampler. The rake is constructed of two rake heads (double rake head) welded together, measuring 13.8 inches (35 centimeters) long with 14 teeth on each side. The handle is 8 ft (2.4 meters) in length, and should include a telescoping extension that results in a total handle length (from tip of rake head to fully extended end) of 15 feet (4.6 meters). You will also need a second, weighted, double rake head on a rope (rake-on-a-rope) to sample deeper sites. See section on “rake construction” for more detail.

2. Using the rake. Collect one rake sample per site: In waters less than 12 feet, handle the rake using the pole. In deeper water, toss the rake-on-a-rope. In either case, try to drag the rake along the bottom for 2.5 feet (0.75 meters). The amount of plants brought up on the rake may vary tremendously. Record each species present and estimate the rake fullness rating (more fully described). Keep two examples of each species found in the lake (see 7. *Collect voucher samples* below). The rake may dislodge plants that will float to the surface, especially short rosette species not easily caught in the rake tines. Record each species present and estimate the rake fullness rating just as you would plants brought up on the rake

3. Point-intercept sampling issues and procedures.

a. Under-sampling near shore. One problem with the grid system is that it may under-sample very shallow sites where the vegetation is often quite different, even from sites just a bit deeper. To compensate for this problem, it is essential that you visit bays and shoreline areas missed by the grid and use the rake to collect and identify. Record any species seen, especially emergent vegetation (rooted in water), and describe near-shore habitats on the Boat Survey sheet. These data will not be tallied in the ENTRY or STATS pages but should be recorded on an electronic version of the Boat Survey Sheet to accompany the other data.

b. Navigational error. When navigating to sites using a handheld GPS unit, remember that there will be inherent error in locating points, sometimes as great as 60 feet. In addition to that error, there remains the question of “How close to the point is close enough?” You will almost never be able to sample a point at 0 feet from the point. Total error from the GPS error and navigational error *combined* should not exceed half of the sampling resolution. To avoid this when navigating using the map screen, navigate at no more than an 80-foot zoom level and completely cover the point with the arrow. At this level, the locational arrow on the screen is ~8 m long. This means that to sample with acceptable accuracy, the arrow must completely cover the point you are trying to hit, with the arrow centered over the point. At coarser zoom – 120-foot and up, even if you are completely covering the point you still may be quite far from the point, just because the arrow is so large in comparison to the size of the points. You may need to navigate at a greater zoom resolution, but, as you approach the target point, switch to the 80-ft zoom resolution to assure you hit your point accurately.

c. Hard-to-reach points. It may be hard to get to some sampling sites, especially in certain bays, where the water is very shallow and the substrate is mucky. When possible and practical, try to get to the point by poling with an oar, but do not spend undue time poling to these shallow sites. Due to safety concerns, field workers should not get out and drag the boat through mucky sediment to reach a site. If the sampling site is shallow but the substrate is firm, you should walk to the site from shore. If you cannot access a site, leave the depth blank and record NA (no access) or “land” (if the site is on land) in the comments column. (Remember to transfer these comments to the ENTRY sheet).

4. Filling out the Field Data sheet. Print the FIELD DATA sheet from the Excel workbook APMstats123.xls for use in the field. We recommend printing the data sheet onto waterproof paper such as Xerox Never Tear Paper.

a. Top portion. Fill out the top portion of the Field sheet with lake name, WBIC, county, and date. Also, record all the observers and how many hours they worked on this lake.

b. Site Number. Each site location is defined by the lat/long data imported onto your GPS unit and each site should have one row of data.

c. Depth. Measure and record the depth at each site sampled, regardless of whether vegetation is present. It is often easiest to mark the pole to establish depth for the shallower sites. However, a variety of options exist for taking depth measurements, including SONAR guns, depth finders that attach to the boat, or depth increments marked on the rope attached to the weighted rake sampler. If using a depth finder, please note that the accuracy decreases greatly in densely vegetated areas—depth will often be given to the top of the vegetation instead of to the lake bottom.

d. Dominant sediment type: Record sediment type (based on how the rake feels when in contact with the bottom) at each site where plants are sampled as: mucky (M), sandy (S), or rocky (R).

e. Pole vs. rope. Record whether the field team held the rake by the pole (P) or rope (R).

f. Species information. Note that the field data entry sheet does not include any species names, except for EWM (Eurasian water-milfoil) and CLP (curly-leaf pondweed). The sampling team must enter the species name the first time that species is encountered. Names will have to be entered again on successive field sheets (as they are encountered). The use of standard abbreviations can greatly shorten this process.

For all species, record the rake fullness rating (1- few, 2- moderate, 3-abundant, see illustration following this text) on the field data entry sheet at each sampling point where it is found. Record rake fullness for filamentous algae as well. Record the rake fullness rating for plants dislodged by, but not collected on the rake (please see “Under-sampling near shore”, above). While at a site, look for any other plants (not already recorded) at that site within 6 ft (2m) of the boat. Record these species as a “visual” (V) on the data sheet. These species will be included in total number of species seen but will not be included in summary statistics. Account for plant parts that dangle or trail from the rake tines as if they were fully wrapped around the rake head.

5. Filling out the Boat Survey Data sheet. Often there will be localized occurrences of certain species (e.g., floating-leaf or emergent species) that are obvious to the viewer but could possibly be missed by the point-intercept grid. As discussed above in “Under-sampling near shore”, you should examine shoreline areas that are out of the grid. While you need not make a separate trip around the entire lake, do visit areas that may be under-sampled and record the information (including the closest sampling point) on the Boat Survey (see APMstats123.xls) and on a lake map. Be sure to create an electronic version of the Boat Survey from the field notes.

6. If no plants are found. If no plants are found at a sampling site while approaching a deep section in the lake, record the depth but do not record any species information. Sample one more (deeper) site beyond that point to ensure that you have correctly identified the maximum plant depth. This should be done for each set of points surrounding the deep portion of the lake. Along any N-S or E-W transect, sampling should continue for at least 2 points beyond the last site with plants. Some sites may not have any plants, even if the site is shallower than the maximum plant depth. For these sites, fill out the data sheet as usual (with no species identified). These sites will be included as sites as deep as, or shallower than, the maximum plant depth.

7. Collect voucher samples. Collect 2 samples of each species found on each lake. These samples must be pressed and dried according to the protocol in Appendix F. Send one prepared specimen to the local DNR office (who will pass them on to a University herbarium). Keep one specimen for the lake group as a reference for future plant identification. If the field team is unable to identify a plant, please try to get fresh plants to the local DNR lake management specialist as it is much easier to identify fresh plants than pressed plants. Be sure to let them know you are sending plants so that they can be processed promptly.

IV. Entering data on the spreadsheets and summary data

The APMstats123.xls Excel workbook has 5 spreadsheets:

- a. READ ME**, with a summary of all the spreadsheets included in the worksheet. The date records the most recent version.
- b. Field Data**, discussed above.
- c. ENTRY**, a data entry sheet for transferring field data to the computer spread sheet. You must transfer all of the information collected in the field to the ENTRY sheet. You should be able to copy the coordinates for the sampling points from the text file you uploaded onto the GPS unit and paste these into the entry sheet. There is a column for comments on the ENTRY sheet.
- d. STATS**, an automated statistics page that provides a summary of the plant data. The summary statistics of the plant survey will automatically appear in the STATS sheet of APMstats123.xls after data are entered in ENTRY.
- e. Boat Survey**, discussed above.

V. Where to Send Data

Send electronic copies of the ENTRY, STATS and Boat Survey to Jen Hauxwell (Jennifer.Hauxwell@dnr.state.wi.us).

Rake Fullness Ratings

Rake fullness ratings are given from 1-3 for each species. Conditions of the ratings are described below:

Rating

Coverage

Description

1



A few plants on rake head

2



Rake head is about ½ full
Can easily see top of rake head

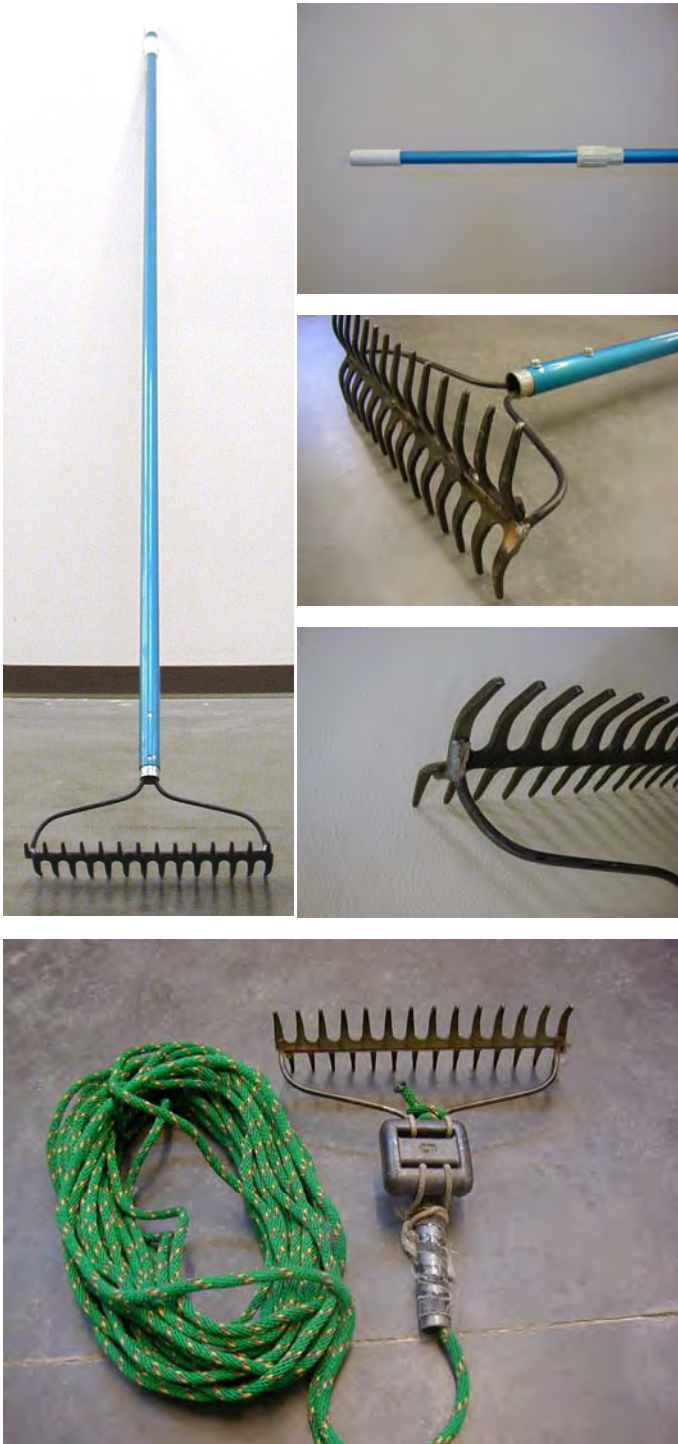
3



Overflowing
Cannot see top of rake head

Rake Construction

Pictures of a rake are shown below, with potential vendors of the components indicated. (These are not endorsements of specific vendors.)



Pole Sampler

The rake sampler is made from two rake heads welded together, measuring 13.8 inches (35 centimeters) long with 14 teeth on each side. This example purchased from Menards with wooden poles attached and subsequently removed).

The handle is 8 ft (2.4 meters) in length, and should include a telescoping extension that results in a total handle length (from tip of rake head to fully extended end) of 15 feet (4.6 meters). This example was purchased from a pool supply company in Madison, WI (Bachmann Pool & Spas).

Rope Sampler

A similar rake head should be constructed for the rope sampler. At the point where the pole would be attached, tie on a rope or anchor line of at least 40 ft in length. If desired, attach a 5 lb weight to the top of the rake (away from the tines) or thread it on the rake rope. This example has a length of steel tubing welded to the rake head to serve as a handle through which is strung ~45 ft of climbing rope.

QUALITY MANAGEMENT PLAN
QUALITY MANUAL
FOR
NORTHERN LAKE SERVICE, INC.

REVISION NUMBER: 0

EFFECTIVE DATE

Prepared By: Thomas R. Priebe

400 North Lake Avenue
Crandon, WI 54520

715/ 478-2777

_____ R.T. Krueger - President and CEO	_____ Date
_____ Thomas R. Priebe - Quality Assurance Officer	_____ Date
_____ Michael De Master - Business Manager	_____ Date
_____ Chris Geske - LIMS Manager	_____ Date
_____ Andrew Ostrowski - Client Serv/Marketing	_____ Date
_____ James Pilgrim - Laboratory Manager	_____ Date
_____ Russ Wolff - Technical Development Specialist	_____ Date
_____ Craig Caselton - Technical Director – Organics	_____ Date
_____ Steven Hefter - Technical Director - Inorganics	_____ Date

TABLE OF CONTENTS

1.0 POLICY STATEMENT

2.0 ORGANIZATION AND RESPONSIBILITIES

- 2.1 Organization Chart
- 2.2 President
- 2.3 Quality Assurance Officer
- 2.4 Laboratory Information Management System Manager
- 2.5 Business Manager
- 2.6 Client Services and Marketing Manager
- 2.7 Laboratory Manager
- 2.8 Branch Manager
- 2.9 Technical Director for Chemical Analyses
- 2.10 Department Supervisors
- 2.11 Technical Staff
- 2.12 Training
- 2.13 Laboratory Capabilities

3.0 QUALITY ASSURANCE OBJECTIVES

- 3.1 Precision
- 3.2 Accuracy
- 3.3 Representativeness
- 3.4 Completeness
- 3.5 Comparability
- 3.6 Detection Limits
- 3.7 External Controls

4.0 SAMPLE HANDLING

- 4.1 Sample Tracking
- 4.2 Sample Acceptance Policy
- 4.3 Sample Receipt Protocols
- 4.4 Storage Conditions
- 4.5 Chain of Custody
- 4.6 Sample Disposal
- 4.7 Field Sampling

5.0 CALIBRATION PROCEDURES AND FREQUENCY

- 5.1 Traceability of Calibration
- 5.2 Reference Standards
- 5.3 General Requirements
- 5.4 Analytical Support Equipment
- 5.5 Instrument Calibration

6.0 TEST METHODS AND STANDARD OPERATING PROCEDURES

- 6.1 SOPs for Sample Management
- 6.2 SOPs for Reagent / Standard Preparation
- 6.3 SOPs for General Laboratory Techniques
- 6.4 SOPs for Test Methods
- 6.5 SOPs for Equipment Calibration and Maintenance
- 6.6 Method Selection

7.0 INTERNAL QUALITY CONTROL CHECKS

- 7.1 Laboratory Quality Control Samples
- 7.2 Method Detection Limits
- 7.3 Selectivity
- 7.4 Method Validation
- 7.5 Proficiency Testing Samples

8.0 DATA REDUCTION, REVIEW, REPORTING AND RECORDS

- 8.1 Data Reduction and Review
- 8.2 Report Format and Contents
- 8.3 Records
- 8.4 Document Control Systems
- 8.5 Confidentiality
- 8.6 Manual integration

9.0 PERFORMANCE AND SYSTEM AUDITS AND FREQUENCY

- 9.1 Internal Laboratory Audits
- 9.2 Management Review

10.0 FACILITIES, EQUIPMENT, REAGENTS, AND PREVENTIVE MAINTENANCE

- 10.1 Equipment and Reference Materials
- 10.2 Documentation and Labeling of Standards and Reagents
- 10.3 Computers and Electronic Data Related Requirements
- 10.4 Preventive Maintenance
- 10.5 Inspection / Acceptance Requirements for Supplies and Consumables

11.0 SPECIFIC ROUTINE PROCEDURES USED TO EVALUATE DATA QUALITY

- 11.1 Laboratory Control Samples
- 11.2 Matrix Spikes / Matrix Spike Duplicates
- 11.3 Surrogate Recoveries
- 11.4 Method Blanks

12.0 CORRECTIVE ACTION

13.0 SUBCONTRACTING AND SUPPORT SERVICES AND SUPPLIES

- 13.1 Subcontracting Laboratory Services
- 13.2 Outside Support Services and Supplies

14.0 REFERENCES

APPENDICES

- APPENDIX A: Initial Demonstration of Capabilities
- APPENDIX B: Method Capability Certification Statement
- APPENDIX C: Internal audit checklist example
- APPENDIX D: NLS final report format example
- APPENDIX E: Essential Quality Control Requirements
- APPENDIX F: Data package review form examples
- APPENDIX G: Project Specific Requirements (if applicable)
- APPENDIX H: Standard Operating Procedures (if applicable)

TABLES AND FIGURES

- Figure 2-1 Organization Chart
- Table 2-1 Northern Lake Service, Inc. – Capabilities
- Figure 2-2 Floor Plan

1.0 POLICY STATEMENT

This Quality Manual summarizes the policies and operational procedures associated with Northern Lake Service, Inc. in Crandon, Wisconsin. Specific protocols for sample handling and storage, chain-of-custody, laboratory analyses, data reduction, corrective action, and reporting are described. Policies and procedures have generally been structured in accordance with the Wisconsin Department of Natural Resources, guidance provided by The NELAC Institute, and applicable EPA requirements, regulations, guidance, and technical standards. This manual has been prepared in accordance with the guidance documents listed in Section 14 of this document. Further details on these policies and procedures are contained in Standard Operating Procedures and related documents. This Quality Management Plan, Standard Operating Procedures, and related documentation describe the quality system of Northern Lake Service, Inc.

Northern Lake Service, Inc. performs chemical analyses for inorganic and organic constituents in water, soil, and solid waste matrices as well as microbiological analyses. The goal of Northern Lake Service, Inc. is to produce data that is scientifically valid, defensible, and of known and documented quality in accordance with standards developed by the Wisconsin Department of Natural Resources, The NELAC Institute, and any applicable state or EPA regulations or requirements.

Northern Lake Service analyzes Proficiency Testing samples semi-annually from a NIST-approved Proficiency Testing provider for the analytes established by the EPA for water samples. The specific analytes and matrices analyzed are based on the current scope of the laboratory services and are documented in a laboratory Standard Operating Procedure on Proficiency Testing sample analyses.

The technical and service requirements of all requests to provide analyses are thoroughly evaluated before commitments are made to accept the work. This includes a review of facilities and instrumentation, staffing, and any special quality control or reporting requirements to ensure that analyses can be performed within the expected schedule. All measurements are made using published reference methods or methods developed by Northern Lake Service. Competence with all methods is demonstrated according to the procedure described in Appendix A prior to use. For projects where data quality objectives differ from established methods or protocols, all reports include a summary of deviations, or a narrative clearly stating data limitations for the end user. For items requiring subcontracting, Northern Lake Service, Inc. will use laboratories that meet the requirements established by the appropriate regulatory body, and the data quality objectives required of the project.

Northern Lake Service has developed a proactive program for prevention and detection of improper, unethical or illegal actions. Components of this program include: electronic data audits and post-analysis data review by laboratory supervisors, client services staff, and the Quality Assurance Officer; a peer-review program of analytical data review; and standard operating procedures identifying appropriate and inappropriate laboratory and instrument manipulation practices.

Client issues are infrequent and are generally received by the Client Service Staff or Laboratory Manager. The majority of items are minor, client-specific issues that require minimal effort to resolve. A record of the issue and its resolution is documented on the sample track and/or LIMS for the specific project. When an issue warrants additional attention, the appropriate manager will convene a meeting of any or all of the following: Laboratory Manager, QA Officer, LIMS Manager, Client Service Manager or Staff, appropriate supervisor(s), or billing agent to discuss the issue and determine the appropriate action. A record of the meeting, or action taken, will be documented on a "Continuous Improvement Request" form. Once resolution of the issue is determined, the Laboratory Manager, Client Service Staff, or other appropriate member of the team will contact the client to discuss how the issue was/is to be resolved. A record of the correction will be filed in the client's file and the client services staff will file the "continuous improvement request" form. At each scheduled marketing meeting the forms will be reviewed to ensure that resolution and continuing improvement have occurred.

2.0 ORGANIZATION AND RESPONSIBILITIES

2.1 Organization Chart

An organization chart for Northern Lake Service is shown in Figure 2-1. This chart includes all individuals discussed below. Job descriptions for all individuals are maintained in the Human Resources Department offices.

Chairman of the Board	Ron K. Krueger
President	Ron T. Krueger
Quality Assurance Officer	Thomas R. Priebe
LIMS Manager	Chris Geske
Business Manager	Michael De Master
Client Serv/Marketing Manager	Andy Ostrowski
Laboratory Manager	James Pilgrim
Technical Development Specialist	Russ A. Wolff
Organics Supervisor	Craig Caselton
Inorganics Supervisor	Steven Hefter
Branch Manager	Mark Milanowski

Northern Lake Service, Inc. is a privately owned and operated business. None of its officers or staff maintains any relationship with other laboratories, industries or regulatory agencies that might cause undue pressure that could adversely affect data.

2.2 President

The President is charged with long-term planning, business strategy and marketing issues, but still maintains a significant role in day-to-day operations. He works closely with middle and upper level management on a variety of regular and special issues. These activities include:

Regularly scheduled

Operations meetings

- Schedule – Biweekly
- Attendees – Business Manager, Client Services/Marketing Manager, Receivables Clerk, Laboratory Manager, Quality Assurance Officer, LIMS Manager.
- Issues –

Lab Manager: current workload, turn-around issues, method development status, instrument status and other technical issues.

Client Services/Marketing Manager: current sales activities, shows attended, clients and prospective clients visited; client requests for new methods, services, upcoming projects; discussion of any recent client complaints or compliments.

Quality Assurance Officer: PE project status and results, deficiencies noted in quality systems, update of status of internal and external document reviews and/or generation, method development status, status of safety issues, regulatory updates.

Business Manager: general business related and human resources issues, i.e. 401 (k), health insurance.

LIMS Manager: reporting formats, data downloading, manipulation and storage, instrument specific data systems, facility monitoring data systems, specific project reporting requirements

Receivables Clerk: specific status of receivables, discussion of credit limits and extension of credit to new and potential clients.

President: general business issues, including contracts, employee status, corporate policies, current industry outlook; specific financial and production performance, and facility/construction issues.

Management Group Meetings

- Schedule – Biweekly
- Attendees – President, Business Manager, LIMS Manager, Client Services/Marketing Manager, Quality Control Officer, Laboratory Manager
- Issues – Develop short, medium, and long-term goals for the company to produce future growth and profitability. Address any laboratory, clerical, or human resources issues that cannot be remedied through established channels of communication. Identify potential business acquisition opportunities, analytical products, or monitoring programs.

Quality Assurance review meetings

- Schedule – quarterly
- Attendees – Quality Assurance Officer, Laboratory Manager
- Issues – Report by QA Officer of status/completion of corrective actions for PE samples; report by QA Officer of internal schedule, cited deficiencies and/or status of corrective actions; any other relevant issues.

Marketing meetings

- Schedule – as required
- Attendees – Client Service/Marketing Manager, Laboratory Manager, Client Services Representatives
- Issues – determine markets and marketing strategies for marketing. Assign tasks. (Additional follow-up meetings are scheduled as needed.) Discussion and determination of additional action on any recent client complaints or issues.

Safety meetings

- Schedule – quarterly
- Attendees – Safety Committee
- Issues – reports of any accidents, schedule of all-staff and specific training programs, reports of internal and external inspections, MSDS update, any other health and safety related issues.

401(k) meetings

- Schedule – quarterly
- Attendees – 401(k) committee
- Issues – review of 401 (k) performance and related issues

“State of the Business” meetings

- Schedule – annual, or more frequently if appropriate
- Attendees – all staff
- Issues – Update by President of general business performance, industry performance, NLS goals; Update on certification status, major rule changes, and regulatory changes by the Quality Assurance Officer; Discussion of achievements and goals by Chairman of the Board, President, and Laboratory Manager.

Unscheduled activities

- Contract review – Review of larger contracts to (1) determine the ability of NLS to perform all required elements and (2) ensure appropriate mutual reward is provided within the contract terms. Activity performed with assistance of Marketing Manager, Laboratory Manager, Chairman of the Board, Business Manager and/or appropriate technical supervisors.
- Hiring – Determination of need for additional management personnel and requirements of position. Review of resumes. Interviewing of perspective hires. Final hiring decision. Activities performed with Laboratory Manager and/or other appropriate technical supervisor/group leader.
- Oversight of coordination of all laboratory systems – Any and all coordination of interaction between specific laboratory systems. Performed informally through constant and continual interaction with the Laboratory Manager, the President provides input and decision-making on day-to-day and long term production issues.
- Instrument purchases – final decision making on purchase of large instruments. This is done with the technical support of the Laboratory Manager, quality control and/or appropriate supervisors and staff.
- Method development issues – Provide direction and decision making before and during the development of new methods.

- Specific client service needs, complaints, etc., involving management staff.
- Personnel issues – addressing specific personnel issues involving management staff, including disciplinary actions, conflict resolution and special employee needs.
- Perform the duties of Laboratory Manager in his absence.
- Maintaining a proactive program for prevention and detection of improper, unethical or illegal actions.

2.3 Quality Assurance (QA) Officer

As shown in Figure 2-1, the QA Officer is independent of direct job involvement and day-to-day operations, and has direct access to the Laboratory Manager, to resolve any dispute involving data quality. The QA Officer serves as the focal point for QA/QC and is responsible for the oversight and/or review of quality control data. He is responsible for auditing the implementation of the Quality System. The QA Officer has sufficient authority to stop work as deemed necessary in the event of serious QA/QC issues. The QA officer is charged with the duty of developing, implementing and monitoring the Quality Control / Quality Assurance program at Northern Lake Service, Inc. This program consists of but is not limited to:

- Ensuring that technical lab staff demonstrate proficiency in the activities for which they are responsible.
- Ensuring that the training of its personnel is kept up-to-date.
- Notifying laboratory management of deficiencies in the quality system and monitoring corrective action.
- Conducting Performance Evaluation studies and reporting results to laboratory management.
- Assisting the Laboratory Manager with any and all activities listed above.
- Method development – This duty is shared with the Laboratory Manager and involves determining all appropriate QC requirements to meet compliance for new methods. It requires communication with appropriate regulators and assembly of data package to satisfy certification requirements.
- Internal sample bottle check program.
- SOP coordination – Development and review of NLS SOP format for compliance and consistency, assignment of SOPs to staff, review of completed SOPs, maintenance and control of SOP manuals.
- Method and in-house quality control compliance – this involves working with supervisors, LIMS, and appropriate staff to ensure that proper quality control levels for blanks, standards, replicates, surrogates, internal standards, spikes and any other required QC data points are determined, measured, recorded, analyzed, and stored and that the required limits generated from these points are properly calculated and utilized.
- Logbook maintenance – This requires determining need for, creating and implementing and reviewing logbooks for compliance with specific program. These logbooks include, but are not limited to temperature logs, reagent preparation logs, analytical run logs, pH monitoring logs, and standard preparation logs. Logbooks are bound, paginated and given a discrete tracking number. When they are completed they are placed in the archives.
- Act as Safety Manager – This program involves chairing the safety committee and running quarterly meetings, maintaining safety related documentation, implementing safety programs and equipment (with final approval by the President).
- Perform internal audits.
- Retain records of traceability.

Regularly scheduled activities:

- Operations meetings – include documented reports to management of quality control issues.
- Management Group meetings.
- Quality control review meetings.
- Safety meetings.

2.4 Laboratory Information Management System Manager

The Laboratory Information Management System (LIMS) Manager oversees the department and assigns projects to the LIMS staff as required. The LIMS Manager participates in the regularly scheduled operations meeting, and is a member of the management group. A general overview of responsibilities includes the following:

- Security of all networked systems, internal and external, including remote access.

- Maintenance and troubleshooting of all networked and stand alone computing systems.
- LIMS database management and backup.
- Maintain and verify integrity of the LIMS database and computer automated procedures.
- Backup and retrieval of all instrument generated raw data.
- Internal document backup and retrieval.
- Third party software evaluation, validation, and approval for use in NLS systems.
- Internal software validation.
- Deployment and training for computing software and hardware.
- Maintenance and troubleshooting of internal phone system.
- Testing and evaluation of new data acquisition systems.
- Design of new LIMS functionality to conform to ever changing regulatory requirements.
- Design of internal software and procedures to aid analysts with raw data review.
- User training and support for LIMS system.

Regularly scheduled activities:

- Operations Meetings.
- Management Group Meetings.

2.5 Business Manager

The Business Manager reports to the President and Chief Executive Officer. The duties include, but are not limited to:

- Administration and coordination of health care plan, HRA health reimbursement plan, COBRA plan, life and disability insurance program, and annual and personal leave program.
- Maintenance of equipment and fixed asset records and preparation of annual property taxes.
- Oversight of daily cash receipts, cash disbursements, accounts payable, and accounts receivable.
- Administration and coordination of 401K retirement plan.
- Preparation of bi-weekly payroll and timely filing of payroll tax and withholding.
- Assemble information for annual corporation tax reports.
- Preparation of monthly and annual financial reports.
- Advise ownership group and management group on company financial matters.
- Supervise office staff and custodian.

Regularly scheduled activities:

- Operations meetings.
- Management Group meetings.
- 401K meetings.

2.6 Client Service and Marketing Manager

The Client Service/Marketing Manager reports to the President. The Manager and staff coordinate quotations for services, bottle orders, and client contacts. He also provides oversight of the field services section. His duties include, but are not limited to:

- Client quotations for services.
- Project Management for specific regulatory programs.
- Marketing strategies and programs
- Client liaison, issues resolution.
- Company representative for trade shows, organizational meetings, and on-site client contacts.
- Technical lead for department quotations.
- Oversee coordination of field sampling projects.
- Final data package review and approval for select programs and clients.
- Daily client contact and interaction.
- Monitoring of subcontracting sources for laboratory analysis.

Regularly scheduled activities:

- Operations meetings.
- Management Group meetings
- Marketing meetings.

2.7 Laboratory Manager

The Laboratory Manager is charged with oversight of day-to-day laboratory operations and shipping/receiving activities. His duties include, but are not limited to:

- Acting as formal liaison between technical staff and management on daily production issues.
- Acting as formal liaison between technical staff and management to ensure that work is appropriately scheduled to meet required holding times and specific client requirements.
- Updating the President, Marketing Manager, Quality Assurance Officer, Client Service Representatives, and any other appropriate personnel of general production activities.
- Preparing or coordinating preparation of non-standard reports/data packages.
- Method development – working with the Quality Assurance Officer, appropriate staff and/or supervisor to facilitate development of new methods/procedures.
- Assisting client service representatives with technical issues in response to specific client needs including double-checking of data points, discussion of specific method, and discussion of quality control data for a specific project.
- Coordinating most determinations of capability and capacity of specific projects with supervisors and other appropriate staff.
- Coordinating sample shipping and receiving, sample login.
- Defining the minimal level of experience and skills necessary for all positions in the laboratory. In addition to education and / or experience, basic laboratory skills are considered.
- Documenting all analytical and operational activities.
- Ensuring that the laboratory has the appropriate resources and facilities to perform requested work.
- Ensuring that corrective actions relating to findings from internal audits are completed.

Regularly scheduled activities:

- Supervisor meetings
- Schedule – Monthly
- Attendees – technical supervisors.
- Issues – Open forum discussion of miscellaneous issues/occurrences, specific training and discussion points, information.
- Operations meetings.
- Quality Assurance review meetings.
- Marketing Meetings.
- State of the Business meetings.

Unscheduled activities

- Assist president with any and all activities listed above as “unscheduled”.

2.8 Branch Manager (Waukesha)

The Waukesha Branch Manager is responsible for daily production operations at that location. He reports directly to the President, but works with appropriate management for any specific operating issues (i.e. quality control, LIMS, personnel). The Waukesha location maintains Wisconsin DNR and Wisconsin DATCP certification and is not NELAC accredited. The Waukesha facility has its own site-specific quality manual.

2.9 Technical Director for Chemical Analyses

The duties of Technical Director of Chemical Analysis are performed by the Laboratory Manager or by the Department Supervisors under the direction of the Laboratory Manager.

2.10 Department Supervisors

The Department Supervisors report to the Laboratory Manager and are responsible for:

- Scheduling and directing technical staff to perform tests appropriate to their skills and training.
- Monitoring workload and assisting technical staff with scheduling in order to ensure adherence to holding times and specific client needs.
- Monitoring the quality and quantity of analyses performed and data generated.
- Monitoring the validity of the analyses performed and data generated in the laboratory to assure reliable data.
- Providing technical assistance for method development and troubleshooting of existing methods.
- Providing educational direction to laboratory staff.
- Acting as information liaison between management and technical staff.
- Performing annual performance reviews of staff.
- Dealing with minor disciplinary issues of their staff.
- Review of selected raw data and all final data reports.
- Performing technical review of incoming projects (sample track/log-in review).
- Assisting Laboratory Manager, Quality Control Officer, and Client Service staff in decisions regarding capability and capacity for specific projects.
- Generating client-specific data/quality control reports.
- Acting with Quality Control Officer to ensure corrective action measures are taken.
- Assisting President and Laboratory Manager in determining necessary and/or appropriate qualification during the hiring of new employees.

Scheduled activities

- Supervisor meetings

2.11 Technical Staff

Technical Staff members are responsible for sample analysis and identification of corrective actions. The staff reports directly to the appropriate supervisor. All personnel are responsible for complying with all quality assurance/quality control (QA/QC) requirements that pertain to their organizational/technical function. As documented in the employee records, (See Appendix C) each Technical Staff member has the experience and education to adequately demonstrate knowledge of their particular function and a general knowledge of laboratory operations, analytical test methods, quality assurance/quality control procedures and records management. Along with technical training, all staff has received appropriate safety training and received training regarding professional ethics and confidentiality. Documentation of this training is on file with the QA Officer.

2.12 Training

Each employee has read, understood, and is using the latest version of the laboratory's Standard Operating Procedures, which relates to his/her job responsibilities. Each employee demonstrates continued proficiency by acceptable performance on Laboratory Control Sample (LCS), Proficiency Testing and internal blind Proficiency Testing Studies. Employees are encouraged to take advantage of outside educational opportunities. These include training sessions at vendor facilities, vendor sponsored seminars and regulatory agency sponsored seminars. Training records (e.g., continuing education, participation in technical conferences, internal training activities) are kept in personal training files.

2.13 Laboratory Capabilities

Northern Lake Service analyzes water, soil, and solid waste samples as well as microbiological samples. Table 2-1 lists the parameters/analytes measured and the associated bottles and preservatives.

3.0 QUALITY ASSURANCE OBJECTIVES

The overall quality assurance objectives for Northern Lake Service are to develop and implement procedures for laboratory analyses, chain-of-custody, and reporting that will provide results of known and documented quality. Data Quality Indicators (DQIs) are used as qualitative and quantitative descriptors in interpreting the degree of acceptability or utility of data. The principal DQIs are precision, bias (accuracy), representativeness, comparability, completeness and detection limits. DQIs are used as quantitative goals for the quality of data generated in the analytical measurement process. This section summarizes how specific quality assurance objectives are achieved. The specific applications of these activities are contained in the method Standard Operating Procedures.

3.1 Precision

Precision is a measure of the degree to which two or more measurements are in agreement.

Precision is assessed through the calculation of relative percent differences (RPD) and relative standard deviations (RSD) for replicate samples. For inorganic and organic analyses, laboratory precision is usually assessed through the analysis of matrix spike/matrix spike duplicate (MS/MSD) and field duplicate samples.

3.2 Accuracy

Accuracy is the degree of agreement between an observed value and an accepted reference or true value.

Accuracy is assessed by the analysis of blanks and through the adherence to all sample handling, preservation and holding times. Laboratory accuracy is further assessed through the analysis of MS/MSD, quality control check samples, laboratory control samples (LCS) and surrogate compound spikes.

3.3 Representativeness

Representativeness expresses the degree to which data accurately and precisely represent a characteristic of a population, parameter variations at a sampling point, a process condition, or an environmental condition within a defined spatial and/or temporal boundary.

Representativeness is ensured by using proper analytical procedures, appropriate methods, sample holding times and analyzing field duplicate samples.

3.4 Completeness

Completeness is a measure of the amount of valid data obtained from a measurement system compared to the amount expected under normal conditions.

Laboratory completeness is a measure of the amount of valid measurements obtained from all the measurements taken in the project. The laboratory completeness objective is to generate valid data for all samples be greater than 95 percent.

3.5 Comparability

Comparability is an expression of the confidence with which one data set can be compared to another.

Comparability is achieved by the use of routine analytical methods, achieving holding times, reporting results in common units, use of consistent detection levels, and consistent rules for reporting data.

3.6 Detection Limits

Method Detection Limits (MDLs) are determined for all analytes as specified by the Wisconsin Department of Natural Resources, as outlined in NELAC documentation, or USEPA standards and guidelines. From these, a Limit of Quantitation

(LOQ), nominally 3.18 times the MDL, is established. The LOQ is the minimum concentration of an analyte that can be identified and quantified within specified limits of precision and bias during routine analytical operating conditions. For projects requiring NELAC accreditation, a method reporting limit (MRL) that is equal to the lowest calibration standard, or appropriate MRL verification standard, will be used in place of the LOQ. Specific procedures are outlined in the Northern Lake Service SOP for the Determination of MDL, LOD, LOQ, and Reporting Limits.

3.7 External Checks

NLS participates in a number of external performance evaluation studies as part of the quality control/quality assurance system. These studies are performed mainly in order to comply with certification requirements. NLS also participates in additional studies to provide further record of our analytical competence if required. A summary of typical blind/PE study participation is provided in Section 7.5.

4.0 SAMPLE HANDLING

The majority of samples received by NLS are collected by the client, or an agent of the client. NLS cannot be responsible for the integrity of sampling procedures performed by non-NLS personnel. However, we do provide specific sampling instructions for certain tests. We also assist clients with sampling plans when more complex procedures are required or holding times are critical. We provide relevant information to sample collection firms (i.e. engineers, consultants) and governmental entities and assume that they employ sound field sampling procedures. An abbreviated version of the NLS field sampling procedure is included in this document as section 4.7. Complete field sampling procedures are found in the NLS SOP entitled "Groundwater Monitoring Standard Procedure".

4.1 Sample Tracking

Upon receipt of samples, NLS applies a unique number to each sample group (NLS project number) and a unique number to each individual sample bottle within the project. Each sample bottle receives a LIMS printed label indicating the project number, sample number, client name, project name and other relevant information. The NLS field label indicates the type of preservative, if any in each sample bottle. Samples are then placed in the appropriate location depending on the type of testing to be performed. The sample and project number is referenced by the LIMS on all bench sheets, sample progress reports and final data report.

4.2 Sample Acceptance Policy – If a sample is out of compliance with any specific sample receipt requirement, the client is contacted. At the client's instruction, the sample will be discarded or analyzed. If certain requirements are specified by program (i.e. SDWA) or client contract, and are not met, the sample is discarded. If it is analyzed, the data will be flagged with following qualifiers:

- A. Samples received at ___ degrees C, which is above protocol of 6° C or less.
- B. Samples received frozen or partially frozen.
- C. Samples not properly preserved per EPA protocol for: (List Analytes).
- D. Samples received in bottles not furnished by NLS. Chemical preservation methods, if used, are unknown.
- E. Samples received beyond EPA holding time for: (List Analytes).
- F. Sampling Date / Time not supplied by client. The actual holding time is unknown to NLS.
- G. Samples received without proper paperwork. (Explain).
- H. Samples not field filtered for dissolved metals (including Hardness). Lab filtered upon receipt, if analyzed.
- I. VOC vials received with headspace, which does not conform to EPA protocol.
- J. Insufficient sample volume to complete analysis.
- K. Sample analyzed beyond EPA recommended holding time due to age of sample upon receipt.
- L. Sample received for XXX did not meet preservation pH requirement of <2 s.u. An additional X aliquot(s) of acid was/were added to sample upon receipt at laboratory and sample then met pH requirements.
- M. Sample received for cyanide analysis did not meet pH preservation requirement of >12 s.u. An additional X tablets of NaOH were added to the sample and pH preservation requirements were met.
- N. Sample received for XXX did not meet pH preservation requirement of <2 s.u. An additional 3 aliquots of acid were added to the sample upon receipt and sample still did not meet preservation requirement.
- O. Sample did not meet preservation pH requirement due to sample matrix.

Where an alternate procedure has been expressly put in place by an individual client, appropriate documentation is made.

4.3 Sample Receipt Protocols

- A. Samples are normally received by United Parcel Service, United States Postal Service, Federal Express, Dunham Express and Speedee Delivery. They are occasionally hand delivered by clients and/or other special couriers, or are brought in by the NLS field crews.
- B. Sample shipping containers are opened in the order they are received. Samples received with ice present in the shipping container are documented as "received on ice". If no ice is present in container, the temperature blank or ice melt water is checked to verify all samples are received within program specified temperature requirements, but not received frozen. If samples are not received on ice, and they have a temperature above 6°

C, or are frozen they are considered in "noncompliance". The noncompliance is documented on the sample track and in the LIMS notes section for non-compliance, and the data is flagged by NLS. Clients are notified of any noncompliant samples and are given the choice of re-sampling or having the analytical data flagged in the final report. For projects with sample receipt requirements differing from those found in NR 149, additional project specific information will be documented (i.e., actual sample receipt temperature for a representative sample per TNI protocol).

- C. The Chain of Custody, and Order of Analysis paperwork is checked to determine if all the correct information is recorded and the appropriate forms are signed. Samples are also considered noncompliant if the paperwork is not filled out correctly with the needed information. The sample receipt time and date is documented on the sample chain of custody paperwork and signed by the receiving staff member. The phrase "on ice" is recorded if ice is present in the cooler; and a temperature reading is taken and recorded if no ice is evident.
- D. The sample bottles in the shipping containers are checked to determine that they have the appropriate volume, and preservatives, for the requested analyses. All VOC vials are checked for headspace. If VOC vials contain air bubbles larger than 10 mm in diameter, clients are notified and the samples are flagged as being "noncompliant". For Safe Drinking Water Act (SDWA) VOC analyses, samples that exceed the 10 mm diameter headspace bubble limit are non-compliant, and clients are notified and required to resample. The pH preservation requirements are verified and documented. For more information on non-compliance, preservation deviations, and client notifications, refer to the NLS sample receipt SOP. All bottles are then organized on the counter in the same order as they are on the client's paperwork for entry into the LIMS and labeling with sample data / number labels.
- E. Samples are then entered into the LIMS computer system using a customer number specific to each client. New clients are assigned a customer number at this time. Each group of samples (organized by client and a combination of specific job site, sample type or parameter list) is assigned a project number by the LIMS computer. Client contact, project name and/or number, and purchase order number are each entered under the project number.
- F. When entering sample data into the LIMS, the following information is entered for each individual sample within a project: number of bottles, sample description or name, collection date and time, received date, sample type, and any other comments relevant to the samples. If a sample or a project requires a "Rush" status, the date that the sample report is requested is entered.
- G. Requested analyses are then assigned to each of the samples. The project is brought to the screen by querying the project number requested. Each analysis in the computer LIMS system has an assigned "Test Code" number. Any analysis can be assigned to a sample by calling up the appropriate "Test Code" number. Some preparatory tests/steps, such as metals digestions, extractions, and solids on solids are automatically assigned if needed.
- H. The Daily Operations (DOPs) computer program is then "expanded". This procedure updates the LIMS and all associated report functions required to monitor laboratory sample throughput are updated.
- I. Labels containing client and collection information are then printed and placed on each individual sample bottle. Sample information, including client, sample description, date and time of collection, sample number, and project number, are included on the label. The NLS project numbers and sample numbers are used to help identify and track the sample through the analytical and review processes. Sample bottle identification codes are unique to each individual bottle received.
- J. All receiving data input is double-checked with the paperwork by someone other than the primary login technician. This verification determines whether all of the samples were logged into the system and that all tests and analyses were added to the appropriate samples.

All sample bottles requiring refrigeration are placed into refrigerated storage at a temperature range of 1-6°C in numeric order according to preservative, for easy retrieval by NLS laboratory staff members. Samples preserved for metals analysis are stored on shelves in the instrument room near the metals analysis area. Samples for volatile organic compound analysis are stored in a separate refrigerator designated only for volatile samples and located on the second floor to help prevent the cross contamination of these samples. Each separate VOC project is bagged for further isolation. Any samples that are obviously highly contaminated are further bagged or packaged to reduce potential contamination.

4.5 Chain of Custody and Sample Security

Each batch of samples is accompanied, from collection through arrival at the laboratory by a standard chain of custody documenting the handling of the samples. Once samples are delivered to the laboratory, sample custody is protected by limited access to sample storage areas. Visitors and service personnel are allowed access only under the supervision of NLS personnel. Internal data “custody” is documented through the NLS “sample track” which is prepared for each project at login. This document records all parties involved in review of the project. The sample track is used in the data package review process outlined in section 8.1 of this document. The computerized database is self-contained on the premises. The computer system does not allow anyone to login without the proper user-ID and password. All access doors to NLS are locked at all times when the premises are vacated. All lab reagents, sample bottles, and lab equipment are stored on the premises. Only full time employees and bonded couriers are allowed unsupervised access to the laboratory.

4.6 Sample Disposal

Samples are retained a minimum of 31 days after completion of the analytical work. (Samples may be retained longer at client request.) All samples are disposed of in compliance with applicable Federal, State and local laws.

4.7 Field sampling (abbreviated)

In addition to laboratory quality control, NLS has standardized field sampling techniques and field quality control. Each time our field sampling crew conducts groundwater sampling, a field equipment blank is processed to evaluate field equipment cleaning procedures.

NLS has devised the following procedure:

1. All equipment is triple rinsed with reagent-grade water. NOTE: This is the standard cleanup procedure between well samples.
2. 500 mL of reagent-grade water is run through the Geofilter pump and filter holder which contain a 0.45 um membrane filter to flush and remove any residual trace contaminants.
3. An appropriate volume of water is placed in the bailer, filtered through the Geofilter filtering system, and collected into new bottles containing the proper preservatives. These samples are then iced.
4. Appropriate field analyses are run and recorded immediately after sample collection. Examples are conductivity, pH, and temperature.
5. Date, time, weather conditions, etc., are recorded for each sample collected.
6. The field equipment blank is logged into the database when received at the lab with all the parameters to be performed on the corresponding samples. This is done to insure there is no possibility of cross-contamination.
7. All meters for field analysis are standardized prior to sample collection. Both the pH and conductivity meters are calibrated before sample collection and at four-hour intervals.

For more detailed field sample collection procedures and protocol, refer to the NLS field sampling plan.

4.8 Representative Samples

Where an entire sample is not consumed during analysis (such as for the analysis of volatile organic compounds), sample containers are mixed prior to analysis. Aqueous samples and those samples that flow are inverted/mixed by hand at least 3 times prior to taking an aliquot. Solid samples are mixed with a clean spatula or other sampling tool to ensure homogenization of the submitted sample.

5.0 CALIBRATION PROCEDURES AND FREQUENCY

5.1 Traceability of Calibration

Wherever applicable, calibration of analytical support equipment and instruments is traceable to national standards of measurement. The appropriate departments maintain records of traceability. Standards used for calibration or verification, and any supplies, reagents, or specific chemicals used for sample preparation or analysis are purchased from reputable sources. These items are verified as being suitable for use through routine method QA/QC measures, historical performance of the materials and suppliers, external certifications or standards with which the supplier adheres to, or internal evaluation by the laboratory.

5.2 Reference Standards - Reference standards of measurement (such as Class S or equivalent weights or traceable thermometers) are used for calibration only. Reference standards are subjected to in-service checks between calibration and verification.

5.3 General Requirements

Instruments are calibrated or the calibration is verified on the day of analysis. A blank and a minimum of three or more calibration standards are generally used to calibrate every instrument. Some methods allow the use of a continuing calibration check standard to assure a previous calibration is still valid. In these cases, the recovery of the check standard must fall within predetermined limits. If this check standard does not meet the limits, the instrument must be recalibrated using a blank and generally at least three calibration standards.

5.4 Analytical Support Equipment

Analytical support equipment includes: balances, ovens, refrigerators, freezers, incubators, water baths, temperature measuring devices and volumetric dispensing devices. All such devices are maintained in proper working order and calibrated using NIST traceable references where available. During each working day refrigerators, freezers, incubators and ovens are checked for compliance with acceptable ranges. Temperatures are recorded in the appropriate logbook. Balances are checked each day if used daily or prior to use if used less frequently. Mechanical dispensing devices are checked quarterly. Acceptance limits are included in each logbook.

5.5 Instrument calibration

1. Mercury by Flameless Atomic Absorption:

All standard calibration curves consist of a blank and five standards and must have a correlation coefficient of 0.995 or greater. Initial calibration is verified by the analysis of an Initial Calibration Verification second source standard. Following calibration, a Laboratory Fortified Blank and a Laboratory Reagent Blank are analyzed with every digestion batch and must recover within method-defined limits. Continuing Calibration Verification standards and Continuing Calibration Blanks are analyzed after every 10 samples and must recover within the method defined limits. Matrix Spikes and Matrix Spike Duplicate samples are analyzed every ten samples and must recover within method defined limits.

2. Metals by ICP OES:

All standard calibration curves consist of a blank and one calibration standard. Initial calibration is verified by the re-analysis of the calibration standard, the analysis of an Initial Calibration Verification second source standard, and the analysis of an Initial Calibration Verification Blank. An Interference check standard is analyzed following calibration to verify the Interelement Correction Factors. Continuing Calibration Verification standards and Continuing Calibration Blanks are analyzed after every 10 samples and must recover within the method defined limits. Matrix Spike and Matrix Spike Duplicate samples are analyzed every ten samples and must recover within method defined limits. Laboratory Fortified Blanks and Laboratory Reagent blanks are analyzed with every digestion batch and must recover within method defined limits. Internal Standards must recover within method-defined limits.

3. Metals by ICP MS:

Prior to calibration, a Daily Test is performed to verify acceptable hardware performance. All standard calibration curves consist of a blank and three calibration standards. Initial calibration is verified by the re-analysis of the three calibration standards, the analysis of an Initial Calibration Verification second source standard, and the analysis of an Initial Calibration Verification Blank. An Interference check standard is analyzed following calibration to verify the correction factors. Continuing Calibration Verification standards and Continuing Calibration Blanks are analyzed after every 10 samples and must recover within the method defined limits. Matrix Spike and Matrix Spike Duplicate samples are analyzed every ten samples and must recover within method defined limits. Internal Standards must recover within method-defined limits.

4. Metals by Atomic Absorption Graphite Furnace:

All standard calibration curves consist of a blank and a minimum of three standards and must have a correlation coefficient of 0.995 or greater. Initial calibration is verified by the analysis of an Initial Calibration Verification second source standard and the analysis of an Initial Calibration Blank. Continuing Calibration Verification standards and Continuing Calibration Blanks are analyzed after every 10 samples and must recover within the method defined limits. Matrix Spike and Matrix Spike Duplicate samples are analyzed every ten samples and must recover within method defined limits. Laboratory Fortified Blanks and Laboratory Reagent blanks are analyzed with every digestion batch and must recover within method defined limits.

5. Mercury by Atomic Fluorescence:

All standard calibration curves consist of a calibration blank and 5 standards. Initial calibration is verified by the analysis of an Initial Calibration Verification second source standard and the analysis of an Initial Calibration Verification Blank. Continuing Calibration Verification standards and Continuing Calibration Blanks are analyzed after every 10 samples and must recover within the method defined limits. Matrix Spike and Matrix Spike Duplicate samples are analyzed every ten samples and must recover within method defined limits. Laboratory Fortified Blanks and Laboratory Reagent blanks are analyzed with every digestion batch and must recover within method defined limits.

6. Wet chemistry by automated segmented flow spectrophotometry:

All standard calibration curves consist of a blank and a minimum of three calibration standards and must have a correlation coefficient of 0.995 or greater. Initial calibration is verified by the analysis of an Initial Calibration Verification second source standard and the analysis of an Initial Calibration Blank. Continuing Calibration Verification standards and Continuing Calibration Blanks are analyzed after every 10 samples and must recover within the method defined limits. Matrix Spike and Matrix Spike Duplicate samples are analyzed every ten samples and must recover within method defined limits. Laboratory Fortified Blanks and Laboratory Reagent blanks are analyzed with every digestion/distillation batch and must recover within method defined limits.

7. Anions by Ion Chromatography:

All standard calibration curves consist of a minimum of four calibration standards and must have a correlation coefficient of 0.995 or greater. Initial calibration is verified by the analysis of an Initial Calibration Verification second source standard, the analysis of an Initial Calibration Blank, and the analysis of an LLOQ standard. The calibration curve is verified prior to every analytical run with an Initial Calibration Verification standard of the same source as the calibration standard. Continuing Calibration Verification standards and Continuing Calibration Blanks are analyzed after every 10 samples and must recover within the method defined limits. Matrix Spike and Matrix Spike Duplicate samples are analyzed every ten samples and must recover within method defined limits.

8. Wet chemistry by manual spectrophotometry:

All standard calibration curves consist of a blank and minimum of three calibration standards and must have a correlation coefficient of 0.995 or greater. Initial calibration is verified by the analysis of an Initial Calibration Verification second source standard and the analysis of an Initial Calibration Blank. Continuing Calibration Verification standards and Continuing Calibration Blanks are analyzed after every 10 samples and must recover within the method defined limits. Matrix spike and Matrix Spike Duplicate samples are analyzed every ten samples and must recover within method defined limits. Laboratory Fortified Blanks and Laboratory Reagent blanks are analyzed with every digestion/distillation batch and must recover within method defined limits.

9. Conductivity by electrometric measurement:
Standardize meter daily using 718 Micromhos/cm @ 25° C conductivity standard. Calibration is verified using a second source standard
10. pH by electrometric measurement:
Calibrate daily using a pH 1 buffer, pH 4 buffer, pH 7 buffer, and pH 10 buffer. The calibration of the meter is verified after calibration using a second source verification standard.
11. Auto Titration (alkalinity):
Standardize the pH electrode using buffers at pH 4 and pH 10. Initial calibration is verified by the analysis of an Initial Calibration Verification second source standard. Matrix Spike and Matrix Spike Duplicate samples are analyzed every ten samples and must recover within method defined limits. A Check Standard is analyzed at the end of the run.
12. Dissolve Oxygen Meter (DO/BOD):
The Dissolved Oxygen meter is calibrated daily by calibrating against fresh RO water.
13. Ion Selective Electrode (ammonia):
The ISE is calibrated using three standards in the low range and four standards in the high range. The calibration is verified by reading all of the calibration standards back along with the analysis of an Initial Calibration Verification second source standard and the analysis of an Initial Calibration Blank. Continuing Calibration Verification standards are analyzed after every 10 sample and must recover within the method defined limits. Matrix Spike and Matrix Spike Duplicate samples are analyzed every ten samples and must recover within method defined limits. Laboratory Fortified Blanks and Laboratory Reagent Blanks are analyzed with every digestion batch and must recover within method-defined limits.
14. Gasoline Range Organics (GRO) and PVOCs analyzed by a Purge and Trap Gas Chromatograph with PID/FID detectors:
The initial calibration curve consists of six calibration standards that must have a linear regression correlation coefficient greater than 0.99. Initial calibration is verified by an Initial Calibration Verification second source standard. Continuing Calibration Verification standards are analyzed after every 20 samples or at the end of the sequence and must recover within method defined limits. Laboratory Control Spike and Laboratory Control Spike Duplicate samples are analyzed with every 10 samples and must recover within method defined limits. Internal Standards must recover within method-defined limits. Surrogate Standards must recover within in-house limits.
15. Volatile Organic Compound (VOCs) 524.2 drinking waters analyzed by a Purge and Trap Gas Chromatograph with a Mass Spectrometer (MS) detector:
BFB is analyzed at the beginning of every 12-hour analytical run sequence. BFB spectra must pass the method-defined criteria. The initial calibration curve consists of six calibration standards that must have a percent RSD less than 20, or a higher regression equation with a correlation coefficient greater than 0.99. Initial calibration is verified by an Initial Calibration Verification second source standard. Continuing Calibration Verification standards are analyzed daily at the beginning of the sequence and must recover within method defined limits. Laboratory Control Spike is analyzed at the end of the sequence and must recover within in-house limits. For Total Trihalo Methanes (THM) an additional Low-Level Laboratory Control Spike is analyzed and must recover within method defined limits. Internal Standards must recover within method-defined limits. Surrogate Standards must recover within in-house limits.
16. Volatile Organic Compound (VOCs) 8260 samples analyzed by a Purge and Trap Gas Chromatograph with a Mass Spectrometer (MS) detector:
BFB is analyzed at the beginning of every 12-hour analytical run sequence. BFB spectra must pass the method-defined criteria. The initial calibration curve consists of six calibration standards that must have a percent RSD less than 15 or a higher regression equation with a correlation coefficient greater than 0.99. Initial calibration is verified by an Initial Calibration Verification second source standard. Continuing Calibration Verification standards are analyzed daily at the beginning of the sequence and must recover within method defined limits. Laboratory Control Spike is analyzed with every 20 samples and must recover within in-house limits. Matrix Spike and Matrix Spike

Duplicate samples are analyzed with every 20 samples and must recover within in-house limits. Internal Standards must recover within method-defined limits. Surrogate Standards must recover within in-house limits.

17. Semi-Volatile Organic Compound (SVOCs) 8270 samples analyzed by Gas Chromatograph with a Mass Spectrometer (MS) detector:
DFTPP is analyzed at the beginning of every 12-hour analytical run sequence. DFTPP spectra and DDT breakdown must pass the method-defined criteria. The initial calibration curve consists of six calibration standards that must have a percent RSD less than 15 or a higher regression equation with a correlation coefficient greater than 0.99. Initial calibration is verified by an Initial Calibration Verification second source standard. Continuing Calibration Verification standards are analyzed daily at the beginning of the sequence and must recover within method defined limits. Laboratory Control Spike and Laboratory Control Spike Duplicate samples are analyzed with every 20 samples and must recover within in-house limits. Matrix Spike sample is analyzed with every 20 samples and must recover within in-house limits. Internal Standards must recover within method-defined limits. Surrogate Standards must recover within in-house limits.
18. Polyaromatic Hydrocarbon (PAH) 8270 water samples analyzed by Gas Chromatograph with a Mass Spectrometer (MS) detector in SIM mode:
DFTPP is analyzed at the beginning of every 12-hour analytical run sequence. DFTPP spectra must pass the method-defined criteria. The initial calibration curve consists of six calibration standards that must have a percent RSD less than 15 or a higher regression equation with a correlation coefficient greater than 0.99. Initial calibration is verified by an Initial Calibration Verification second source standard. Continuing Calibration Verification standards are analyzed daily at the beginning of the sequence and must recover within method defined limits. Laboratory Control Spike and Laboratory Control Spike Duplicate samples are analyzed with every 20 samples and must recover within in-house limits. Matrix Spike sample is analyzed with every 20 samples and must recover within in-house limits. Internal Standards must recover within method-defined limits. Surrogate Standards must recover within in-house limits.
19. Semi-Volatile Organic Compound (SOC) 525.2 drinking water samples analyzed by Gas Chromatograph with a Mass Spectrometer (MS) detector:
DFTPP is analyzed at the beginning of every 12-hour analytical run sequence. DFTPP spectra and Endrin/DDT breakdown must pass the method-defined criteria. The initial calibration curve consists of six calibration standards that must have a percent RSD less than 30 or a higher regression equation with a correlation coefficient greater than 0.99. Initial calibration is verified by an Initial Calibration Verification second source standard. Continuing Calibration Verification standards are analyzed daily at the beginning of the sequence and must recover within method defined limits. Laboratory Control Spike sample is analyzed with every 20 samples and must recover within in-house limits. Matrix Spike and Matrix Spike Duplicate samples are analyzed with every 20 samples and must recover within in-house limits. Internal Standards must recover within method-defined limits. Surrogate Standards must recover within in-house limits.
20. Endothall 548.1 drinking water samples analyzed by Gas Chromatograph with a Mass Spectrometer (MS) detector:
DFTPP is analyzed at the beginning of every 12-hour analytical run sequence. DFTPP spectra must pass the method-defined criteria. The initial calibration curve consists of five calibration standards that must have a percent RSD less than 30 or a higher regression equation with a correlation coefficient greater than 0.99. Initial calibration is verified by an Initial Calibration Verification second source standard. Continuing Calibration Verification standards are analyzed daily at the beginning of the sequence and must recover within method defined limits. Laboratory Control Spike and Laboratory Control Spike Duplicate samples are analyzed with every 20 samples and must recover within in-house limits. Matrix Spike sample is analyzed with every 20 samples and must recover within in-house limits. Internal Standards must recover within method-defined limits. Surrogate Standards must recover within in-house limits.
21. Carbamates 531.1 drinking water samples analyzed by High Pressure Liquid Chromatograph with post column derivatizer and FLD detector:
Laboratory Performance Check is analyzed at the beginning of the sequence and must pass method-defined criteria. The initial calibration curve consists of three calibration standards that must have a liner regression correlation coefficient greater than 0.99. Initial calibration is verified by an Initial Calibration Verification second source

standard. Continuing Calibration Verification standards are analyzed after every 20 samples or at the end of the sequence and must recover within method defined limits. Matrix Spike and Matrix Spike Duplicate samples are analyzed with every 20 samples and must recover within in-house limits.

22. Glyphosate 547 drinking water samples analyzed by High Pressure Liquid Chromatograph with post column derivatizer and FLD detector:

The initial calibration curve consists of three calibration standards that must have a liner regression correlation coefficient greater than 0.99. Initial calibration is verified by an Initial Calibration Verification second source standard. Continuing Calibration Verification standards are analyzed after every 20 samples or at the end of the sequence and must recover within method defined limits. Laboratory Control Spike and Laboratory Control Spike Duplicate samples are analyzed with every 20 samples and must recover within in-house limits. Matrix Spike sample is analyzed with every 10 samples and must recover within in-house limits.

23. Diquat 549.2 drinking water samples analyzed by High Pressure Liquid Chromatograph and DAD detector:

The initial calibration curve consists of three calibration standards that must have a liner regression correlation coefficient greater than 0.99. Initial calibration is verified by an Initial Calibration Verification second source standard. Continuing Calibration Verification standards are analyzed after every 8 hours or at the end of the sequence and must recover within method defined limits. Laboratory Control Spike and Laboratory Control Spike Duplicate samples are analyzed with every 20 samples and must recover within in-house limits. Matrix Spike sample is analyzed with every 10 samples and must recover within in-house limits.

24. EDB/DBCP 504.1 drinking water samples analyzed by Gas Chromatograph and ECD detector:

The initial calibration curve consists of five calibration standards that must have a liner regression correlation coefficient greater than 0.99. Initial calibration is verified by an Initial Calibration Verification second source standard. Continuing Calibration Verification standards are analyzed after every 10 samples or at the end of the sequence and must recover within method defined limits. Low-Level Laboratory Control Spike is analyzed and must recover within in-house limits. Matrix Spike and Matrix Spike Duplicate samples are analyzed with every 10 samples and must recover within method defined limits.

25. Multi-Response Pesticides and PCBs 505 drinking water samples analyzed by Gas Chromatograph and ECD detector:

The initial calibration curve consists of five calibration standards that must have a liner regression correlation coefficient greater than 0.99. Initial calibration is verified by an Initial Calibration Verification second source standard. Continuing Calibration Verification standards are analyzed after every 10 samples or at the end of the sequence and must recover within method defined limits. Matrix Spike and Matrix Spike Duplicate samples are analyzed with every 10 samples and must recover within method defined limits.

26. Haloacetic Acids (HAA) 552.2 drinking water samples analyzed by Gas Chromatograph and ECD detector:

Laboratory Performance Check/Low-Level Laboratory Control Spike is analyzed at the beginning of the sequence and must pass method-defined criteria. The initial calibration curve consists of five calibration standards that must have a liner regression correlation coefficient greater than 0.99. Initial calibration is verified by an Initial Calibration Verification second source standard. Continuing Calibration Verification standards are analyzed after every 10 samples or at the end of the sequence and must recover within method defined limits. Matrix Spike and Matrix Spike Duplicate samples are analyzed with every 10 samples and must recover within method defined limits. Internal Standards must recover within method-defined limits. Surrogate Standards must recover within method-defined limits.

27. Nitrogen Phosphorus Pesticides (NP) 8141 samples analyzed by Gas Chromatograph with a Nitrogen Phosphorus detector:

The initial calibration curve consists of six calibration standards that must have a linear regression correlation coefficient greater than 0.99. Initial calibration is verified by an Initial Calibration Verification second source standard. Continuing Calibration Verification standards are analyzed after every 10 samples or at the end of the sequence and must recover within method defined limits. Laboratory Control Spike and Laboratory Control Spike Duplicate samples are analyzed with every 20 samples and must recover within in-house limits. Matrix Spike

sample is analyzed with every 20 samples and must recover within in-house limits. Surrogate Standards must recover within in-house limits.

28. Organochlorine Pesticides (OC) 8081 samples analyzed by Gas Chromatograph with an Electron Capture Detector:
The initial calibration curve consists of five calibration standards that must have a linear regression correlation coefficient greater than 0.99. Initial calibration is verified by an Initial Calibration Verification second source standard. Continuing Calibration Verification standards are analyzed after every 10 samples or at the end of the sequence and must recover within method defined limits. Laboratory Control Spike and Laboratory Control Spike Duplicate samples are analyzed with every 20 samples and must recover within in-house limits. Matrix Spike sample is analyzed with every 20 samples and must recover within in-house limits. Surrogate Standards must recover within in-house limits.
29. Polychlorinated Biphenyls (PCBs) 8082 samples analyzed by Gas Chromatograph with an Electron Capture detector:
The initial calibration curve consists of five calibration standards that must have a linear regression correlation coefficient greater than 0.99. Initial calibration is verified by an Initial Calibration Verification second source standard. Continuing Calibration Verification standards are analyzed after every 10 samples or at the end of the sequence and must recover within method defined limits. Laboratory Control Spike and Laboratory Control Spike Duplicate samples are analyzed with every 20 samples and must recover within in-house limits. Matrix Spike sample is analyzed with every 20 samples and must recover within in-house limits. Surrogate Standards must recover within in-house limits.
30. Diesel Range Organics (DRO) samples analyzed by Gas Chromatograph with FID detectors:
The initial calibration curve consists of five calibration standards that must have a linear regression correlation coefficient greater than 0.99. Initial calibration is verified by an Initial Calibration Verification second source standard. Continuing Calibration Verification standards are analyzed after every 20 samples or at the end of the sequence and must recover within method defined limits. Laboratory Control Spike and Laboratory Control Spike Duplicate samples are analyzed with every 20 samples and must recover within method defined limits. Surrogate Standards must recover within in-house limits.
31. Total Organic Carbon (TOC) samples analyzed by TOC analyzer with NDIR detector:
The initial calibration curve consists of a blank and six calibration standards that must have a linear regression correlation coefficient greater than 0.99. Initial calibration is verified by an Initial Calibration Verification second source standard. Continuing Calibration Verification standards are analyzed after every 10 samples or at the end of the sequence and must recover within method defined limits. Laboratory Control Spike sample is analyzed with every 10 samples and must recover within method defined limits. Matrix Spike and Matrix Spike Duplicate samples are analyzed with every 20 samples and must recover within in-house limits

This information is provided as an overview of the major analyses performed in the laboratory. The most up-to-date information is included in the individual SOP's for each specific method or analyte. Current LOD/LOQ information is available directly through the LIMS system. Current quality control limits are also available directly through the LIMS system.

6.0 TEST METHODS AND STANDARD OPERATING PROCEDURES

NLS produces, maintains and reviews Standard Operating Procedures (SOPs) that reflect all laboratory activities.

6.1 SOPs for Sample Management

All aspects of physical sample management including receipt, login and storage, are described in the Sample Receiving SOP. Aspects of electronic sample management are addressed in the LIMS SOP.

6.2 SOPs for Reagent / Standard Preparation

All steps involved in the preparation and storage of standards and reagents are included in the method SOP in which the standard or reagent is used.

6.3 SOPs for General Laboratory Techniques

These SOPs describe essentials of operations that are not otherwise addressed elsewhere.

6.4 SOPs for Test Methods

SOPs are initiated by lead chemist/analyst of each individual test, often with the assistance of their supervisor and/or the Quality Control Officer. They are then reviewed and signed-off by the supervisor, the Laboratory Manager or President and the Quality Control Officer. The QA Officer maintains current SOP's in hard copy, and additional copies are available in the appropriate analytical area. They are also available on-line via the NLS intranet. SOPs are reviewed annually by the user, revised if necessary, and the review is documented.

Following is the format used by NLS for all method SOPs:

METHOD TITLE

METHOD SCOPE AND APPLICATION

- A. Component (s)/Matrix or Matrices
- B. NLS Test Codes/Descriptions
- C. Detection Limit(s)
- D. Personnel Qualifications

REFERENCES

- A. EPA, Standard Methods, or other Procedural Reference Source

METHOD SUMMARY

- A. Principles and Theories

DEFINITIONS

INTERFERENCES

- A. Matrix/Chemical Interferences

SAMPLE COLLECTION/PRESERVATION /SHIPMENT/STORAGE

- A. Bottle Preparation
- B. Preservation
- C. Storage
 - 1. Refrigeration
 - 2. Ambient

- 3. Flammable Area
- D. Holding Times
 - 1. Extraction/Digestion
 - 2. Analysis Requirements

SAFETY

- A. Special Precautions
 - 1. Laboratory Arrangement
 - 2. Chemicals
 - 3. Personal

EQUIPMENT, MATERIALS, SUPPLIES

- A. Digestion Extraction/Preparation Equipment
- B. Glassware
 - 1. Specifications
 - 2. Preparation

REAGENTS AND STANDARDS

- A. Reagent Purity Specifications
- B. Standards Preparation Directions
- C. Storage Conditions
- D. Shelf Life

SAMPLE PREPARATION PROCEDURE

- A. Extraction/Digestion/Preparation
- B. Sample Clean-up
 - 1. Interference Reduction
- C. Final Sample Preparation
 - 1. Concentration Specifications
 - 2. Dilution Requirements

INSTRUMENT ANALYSIS PROCEDURE

- A. Instrument Settings
 - 1. Component Specifications
 - 2. Computer Hardware and Software
- B. Stabilization
- C. Calibration
- D. Sample/Standard Presentation to Instrument

CALCULATIONS

- A. General Calculations
 - 1. Peak Area
 - 2. Peak Height
 - 3. Hard-copy Printout (Chart paper, chromatograms, etc.)
- B. Significant Figures
- C. Special Adjustments for Samples
 - 1. Sample Size
 - 2. Sample Matrix
 - 3. Sample Dilution

METHOD PERFORMANCE

- A. There are several requirements that must be met to insure that this procedure generates accurate and reliable data. A general outline of requirements has been summarized below. Further specifications may be found in the NLS Quality Manual and specific SOPs.
 - 1. The analyst must read and understand this procedure with written documentation maintained in his/her training file.
 - 2. An initial demonstration of capability (IDC) must be performed. A record of the IDC will be maintained in the analyst's training file with authorization from the Laboratory Manager and Quality Assurance Officer.
 - 3. An annual minimum detection limit (LOD) study will be completed for this method and whenever there is a major change in personnel or equipment.
 - 4. Periodic performance evaluation (PE) will be analyzed to demonstrate continued competence.

QUALITY CONTROL

- A. Standards
- B. Lab Control Standard (Verification Standard)
- C. Sample QC
 - 1. Accuracy measurements (spike percent recovery).
 - 2. Precision measurements (duplicated – relative percent difference).
 - 3. Surrogate measurements (percent recovery range).
- D. Analytical Limitations
 - 1. Sample Interferences
 - 2. Instrument Limitations
- E. Method Validation and (LOD) MDL Study Procedure
- F. Data Assessment and QC Acceptance Criteria
 - 1. Data will be assessed using the QC Acceptance Criteria from either the NLS LIMS QC Control Limits, from the NLS Quality Manual or from special project/client requirements
 - 2. Sample Acceptance Criteria for this procedure
 - a. Lab Control Sample
 - b. Continuing Calibration Verification
 - c. Blanks
 - d. Duplicates
 - e. Spikes
 - f. Surrogates
- G. Corrective Actions for Out of Control Data
- H. Contingencies for Handling Out of Control/Unacceptable Data
 - 1. Anomaly/Incident Reports

RECORDS AND REPORTING DATA

- A. Bench-sheets and logbook entry
- B. Units/Significant Figures
- C. Detection Limits and Reporting Limits
- D. Qualifiers or comments used if data is to be flagged
- E. LIMS Entry
- F. Client Reports
- G. Data Archiving or Filing

CLEAN UP / POLLUTION PREVENTION / WASTE MANAGEMENT

- A. Lab Work Area
- B. Sample Disposal
- C. Equipment/Glassware

- D. Pollution Prevention encompasses any technique that reduces or eliminates the quantity or toxicity of waste at the point of generation. Numerous opportunities for pollution prevention exist in the laboratory operation. The EPA has established a preferred hierarchy of environmental management techniques that places pollution prevention as the management option of first choice. Whenever feasible, laboratory personnel should use pollution prevention techniques to address their waste generation. When wastes cannot be feasibly reduced at the source, the EPA recommends recycling as the next best option.
- E. The quantity of chemicals purchased will be based on expected usage during its shelf life and disposal costs of unused material. Actual reagent preparation volumes should reflect anticipated usage and reagent stability. Standard and reagent stability will be assessed over time and their replacement gauged by the analytical accuracy and precision.
- F. The EPA requires that laboratory waste management practice be conducted consistent with all applicable rules and regulations. Excess reagents, samples, and method process wastes should be characterized and disposed of in an acceptable manner. The agency urges laboratories to protect the air, water, and land by minimizing and controlling all releases from hoods, and bench operations, complying with the letter and spirit of any waste discharge permit and regulations, and by complying with all solid and hazardous waste regulations, particularly the hazardous waste identification rules and land disposal restrictions.

MAINTENANCE/TROUBLESHOOTING

- A. Preventive Maintenance Procedures and Frequency
- B. Troubleshooting Procedures

ATTACHMENTS

- A. Compound/Analyte List and LODs
- B. Worksheets or forms for recording data
- C. Standard Operating Procedure Summary Sheets
- D. Tables and Diagrams
- E. Validation Data

6.5 SOPs for Equipment Calibration and Maintenance

Calibration and maintenance for each instrument is found within the specific SOP.

6.6 Method selection

All NLS methods are selected from authoritative sources unless specifically requested otherwise by a client or regulatory entity. Analytical methods are cited on bench sheets and on the final data report. In the case where a non-standard method is employed, deviations from the standard method are described on the final report. In appropriate cases, a comment is included on the final report that the data is not to be used for regulatory compliance due to deviation from method specified requirements. Methods are generally chosen based on matrix type, regulatory program and/or detection limit requirements.

A list of authoritative sources used for development of NLS SOPs is included in this document as Section 14 - References

7.0 INTERNAL QUALITY CONTROL CHECKS

7.1 Laboratory Quality Control Samples

The data acquired from QC procedures are used to estimate the quality of data, to determine the need for corrective action in response to deficiencies, and to interpret results after corrective action has been taken. All quality control standards and materials are procured from a reliable, reputable source. Each method SOP contains a section outlining minimal QC requirement. The majority of analytical bench sheets contain current quality control limits on the cover sheet. In general, the following protocol is used except where specific method or project requirements dictate otherwise:

- A) Method blanks are performed at frequency of one per analytical batch and at the end of each set of 20 samples, if applicable.
- B) Laboratory control samples are performed at a frequency of one per analytical batch and at the end of any set of 20 samples, if applicable.
- C) Matrix spikes are performed at a frequency of one in every batch of 10 samples
- D) Surrogates and/or internal standards are added to each sample where required by the method.
- E) Matrix spike duplicates are analyzed at a frequency of one in every batch of ten samples.

7.2 Limit of Detection

In order to insure accurate and consistent results, Northern Lake Service uses various methods that have been studied and proven to be reliable. Detection limits used by Northern Lake Service are updated frequently. Detection limits when determined using the method described by the USEPA per 40CFR part 136, are derived by conducting a replicate analysis with a minimum of seven samples. These samples are spiked and diluted to the proper volume. The samples are digested/extracted (where applicable) and analyzed as if they were an actual sample. The average response and standard deviation is calculated and the method detection limit is calculated as the product of the student t-value times the standard deviation of the test using a 99 % confidence level. The reported limit of detection (LOD) is generally the same as these calculated method detection limits (MDLs).

Where methods and/or regulatory programs require procedures other than 40 CFR part 136, the appropriate method reporting limit (MRL) procedure is employed. Reports generated for TNI compliant projects use the lowest calibration standard, or appropriate MRL verification standard, as the LOQ for reported data.

7.3 Selectivity

- A) Absolute and relative retention times aid in the identification of components in chromatographic analysis and help evaluate the effectiveness of a column to separate constituents. Acceptance criteria for retention time windows are documented in each method SOP.
- B) A confirmation is performed to verify a compound identification when positive results are detected on a sample. Such confirmations are performed on organic tests except when the analysis involves the use of a mass spectrometer or when they are expressly excluded from a method (i.e. WI GRO)

7.4 Method Validation

Method validation includes completion of analyst training requirements, IDC and other validation steps as prescribed by the method or specific regulators (i.e., Wisconsin DNR – Integrated Science Services staff auditors). The Quality Assurance Officer and/or the analyst performing the test maintain all validation information.

7.5 Proficiency Testing samples

Northern Lake Service participates in the following Proficiency Testing studies annually:

- 1) Water-Supply (WS) Proficiency Testing Samples for Drinking Water Annual Lab Certification - January/July
- 2) Water Pollution (WP) Proficiency Testing Samples for Waste Water Annual Lab Certification - January/July
- 3) Water Microbiology (Bacteriological) Certification Samples - March
- 4) Water Microbiology (Bacteriological) Certification Samples - October

8.0 DATA REDUCTION, REVIEW, REPORTING AND RECORDS

8.1 Data Reduction and Review

Log-in / data review is as follows:

1. Someone other than the primary login technician performs login review. Review is focused on typographical errors, client information, sample date and time, chain of custody number and test assignment. Review is performed using submitted paperwork (COC, Order of Analysis, etc.), NLS sample track, and various review reports available through the LIMS.
2. Special project requirements are noted on the sample track and appropriate staff members are notified. Specific information, or requirements, of individual analyses can be added to relay information directly to the analyst at the bench sheet level. Any additional notes may also be entered into the LIMS system on a client specific, or project specific basis.
3. The organic and/or inorganic supervisor, or Field Operations Coordinator then reviews the project for additional test assignment and other technical items. This review is performed using submitted paperwork, LIMS "quick report", LIMS "samples in house" report. Or other available LIMS tools (see appendix I).
4. All analytical work is performed per bench sheets and/or load lists generated from the LIMS for each specific test code or test group. The first page of the standard NLS bench sheet contains method citation information, all current quality control limits, and space for the analyst to record quality control data generated during the analytical run (see appendix I). Quality control data is checked against the limits listed on the form, documented there and entered into LIMS. For many organics and metals tests, where a large amount of data and quality control information is generated, computer programs are used to directly load the data into LIMS. These programs and the manual-entry program are designed to immediately notify the analyst if data is outside of established limits.
5. Data is calculated, reviewed and entered into the LIMS system by the analyst who performs the testing. Most final data is generated either by the individual instrument software, an in-house calculation program (known as "Quantit"), or spreadsheets. Formulae used in these calculations are regularly checked through manual calculation where possible and documented on the data sheets.
6. Data is then reviewed by a peer having technical capabilities similar to the analyst. This review focuses on calculations, quality control limits, dilution factors, etc. Review of calculations, data reduction, and quality control requirements is performed from raw data. Review for transcription errors is performed using the "entered today" form generated by LIMS immediately following data entry. This form is reviewed against raw data and attached to the data package.
7. The Quality Assurance Officer, Client Service Manager, Laboratory Manager, or other designee reviews final reports. Data points within a sample are compared to each other (i.e., TKN greater than ammonia) and data points are compared to previous data from the same sample points, if available. Holding times are checked to ensure all samples were performed within EPA or other applicable requirements. The sample track is reviewed to ensure that any project-specific requirements have been met. Review is performed from submitted paperwork, NLS order of analysis and NLS generated sample track. Errors are corrected by the reviewer, supervisor, or Laboratory Manager. The correction process is fully documented within the LIMS and a record of the original result, new result, the person making the change, the date of the change, and the reason for the change are recorded and maintained.
8. When raw data is ready to be archived, the Quality Assurance Officer, or designee, review a percentage of the data packages for accuracy and completeness.

8.2 Report format and contents

NLS generates several different report final report formats depending on specific client and/or regulatory agency needs. These formats are included as Appendix D. NLS also produces reports in several different electronic formats including DNR TAD, Excel Spreadsheets, ASCII comma-quote delimited files, EQUIS, and EPA CDX UCMR. The LIMS system also has the option of emailing sample receipt confirmations to customers.

8.3 Records

The following records are maintained on-site for a minimum of five years by Northern Lake Service:

1. Sample logbook.
2. Sample raw data processed so that any sample may be traced back to the analyst, date collected, date analyzed, method used, raw data, calculations, results and final report.
3. Quality control data for spikes, duplicates, reagent blanks, reference samples, calibration standards, and known standards.
4. Quality control records for precision and accuracy.
5. Instrument maintenance records.
6. Sample preservation checks of in-coming samples.
7. Status of samples on arrival.
8. Log books, bench sheets, and method demonstration.
9. Chain-of-custody.
10. If NLS does the sampling, the following records are kept on file:
 - A. Preservation used.
 - B. Sampling technique.
 - C. Whether sample was equal volume, time-proportionate or composite-proportionate to flow.
 - D. Whether groundwater samples were field filtered, and the pore size diameter of the filter, (i.e., 0.45 um).
 - E. Any unusual circumstances that may affect result interpretation.
 - F. Field sample results.
 - G. Calibration curves for field instruments, standard conditions, and appropriate maintenance.
 - H. Location and time of sampling.
 - I. Name of sampler.

All final reports, including NLS data report, sample track, and chain of custody are retained in hard copy indefinitely. (NLS has these materials for all projects since the inception of the company.) All raw data is retained in hard copy for 7 years. It is then shredded and a record of destruction is maintained. Raw data for specific projects is maintained longer or indefinitely if required by contract. Final data from September 1991 to current is also available electronically in the LIMS.

For standard projects, all client contacts are noted on the internal chain of custody, or NLS sample track. For more complex projects, high-profile projects or at specific client request a specific project file will be developed and maintained by the Laboratory Manager. Records of any correspondences pertaining to the project (including hard copies of emails, written notes documenting telephone conversations, faxes, and returned sample receipt forms) will be kept in this file. This file will be archived on-site after completion of each project.

Upon the sale of NLS a clause would be included that the new owner agree to retain the above named documents as least as long the current NLS retention period. Upon bankruptcy or other "quitting business" situation, a receiver would be named by the court to retain the above named records for an appropriate period to be determined by the court.

8.4 Document Control Systems

The NLS Quality Management Plan - Quality Manual, and all NLS SOPs are generated in-house and controlled by the QA Officer. They are reviewed annually, updated as necessary and updates are documented. The appropriate supervisor, the Laboratory Manager, and the QA Officer review all SOPs. All SOPs receive a "controlled copy" number assigned and tracked by the QA Officer. Controlled copies for the laboratory are updated at this time as well. "Uncontrolled" copies, which may be provided to regulators or clients, are not updated. The quality manual and relevant SOPs are available to the staff in a number of convenient locations. All laboratory notebooks, reagent and standard preparation logs, extraction logs, analysis logs, and maintenance logs are bound and paginated. All such books are assigned a specific identification number, and are archived upon completion, or update.

8.5 Data Confidentiality / Security

The results of all analyses are confidential. Data are only released to the client, or to an agent of the client if NLS has received prior written, or verbal, authorization from the client. Exceptions to this may include court-subpoenaed information,

or data subjected to the laboratory technical audit process per NR 149, or other relevant regulatory audit procedure. Data generated for public water supply systems for SDWA compliance reporting is electronically submitted to the regulating bodies as required.

(The following sections are from the LIMS SOP)

A. LIMS Server Security

1. All access to the NLS LIMS is password protected.
2. Accounts are only assigned to employees who require database access.
3. Employees shall logoff of the NLS LIMS when they have completed their work session.
4. Super-user and Oracle Database Administrator passwords are only known by the LIMS department, a copy of these passwords are kept in a safe deposit box in case of emergency.
5. Only NLS employees are allowed access to the computers on NLS property.

B. Internet Security

1. A hard firewall prohibits unauthorized access from the Internet.
2. NLS employees may access the LIMS server only when provided with the appropriate account and password information, and only with the approval of the LIMS staff.
3. Customers may access the NLS Online information service only when they are provided with an account and password. They will only be allowed access to their own data.
4. Full system backups are performed routinely. Word processing files are backed up on a weekly basis. Raw data files are archived onto DVD-ROM. Database files and applications are backed up nightly along with a full export of the database. Database backup is performed automatically using the cron scheduling command of the Linux Operating System. The database backup is stored off location on a nightly basis. All other backups are done manually. The manual backup routine is outlined in section VI-G-1-a of this document. All raw data backups are stored in a safe deposit box at the local bank.

8.6 Manual Integration

All NLS staff members receive ethics training, which includes information on manual integration of chromatographic peaks. The Northern Lake Service, Inc. "Manual Chromatographic Peak Integration" SOP details in full the practices and policies of NLS in regard to this issue.

9.0 PERFORMANCE AND SYSTEMS AUDITS AND FREQUENCY

9.1 Internal Laboratory Audits

The Quality Assurance Officer, or his designee, arranges internal audits of all quality control systems. The audit consists of review of systems documents and technical review of analyses performed. The QA Officer performs technical audits, with assistance from the Laboratory Manager, President, or other designee. The QA Officer retains records of the audits, cited deficiencies and corrective actions. Appendix C shows one example checklist used for internal audits. This checklist is a guide and is used in conjunction with knowledge of technical methods by those performing the audits. Cited deficiencies will be reported to upper management as soon as they are discovered. Specific corrective actions for cited deficiencies and the status of their completion are reported to the president at quarterly quality control review meetings. The president will sign off on the corrective action form when the deficiency has been satisfactorily corrected.

9.2 Management Review

In addition to bi weekly operations meetings, the Quality Assurance Officer will meet with the President and Laboratory Manager quarterly to specifically assess the suitability and effectiveness of the quality systems. Changes, additions and improvement will be discussed and implemented. The QA Officer retains records of these meetings.

10.0 FACILITIES, EQUIPMENT, REAGENTS, AND PREVENTATIVE MAINTENANCE

NLS facilities are designed and maintained in order to provide a safe and healthy work environment for employees, minimize the potential for cross contamination and provide the most efficient work processes without compromising data quality.

10.1 Equipment and Reference Materials

Northern Lake Service always strives to utilize the most modern equipment available in the environmental analysis field. Many hours of evaluation and testing go into any equipment purchase. The following is a list of major analytical equipment used at Northern Lake Service, Inc.

General Laboratory Equipment

- Sartorius analytical balance
- Mettler-Toledo AT200 analytical balance
- Blue-M Magni-Whirl constant temperature water bath
- American Scientific Products Model DX-38 drying oven
- Thermolyne 6000 laboratory muffle furnace
- Lindberg/Blue drying oven
- YSI 5100 D.O. meter
- Hach Ratio/XR Turbidimeter
- Accumet pH meter
- Precision Scientific Inc. steam bath
- Baxter S/P Brand ultrasonic cleaner (2)

Sample Preparatory Equipment

- Organomation N-evap nitrogen evaporator
- Westco Easy-Dist distillation system
- AimLab 600 50 position digestion block and controller
- ABC Gel Permeation Chromatography (GPC) system
- Environmental Express Hot Block metals digestion block and controller (4)
- Horizon Technologies Spe-Dex 4790 extractor

Inorganic Analytical Instrumentation

- Spectronic Genesys 2 spectrometer
- Teledyne Tekmar TOC Fusion Analyzer
- Bran + Lubbe AutoAnalyzer 3 segmented flow analyzer
- Thermo Orion model 960/940 autotitrator with AS300 autosampler
- Horizon Technologies 3000XL Oil and Grease Machine
- Bausche and Lomb spectrophotometer
- Dionex ICS-2500 Ion Chromatography System, with elluent generator
- Dionex DX-500 Ion Chromatography System
- Astoria 2 segmented flow analyzer
- Astoria 2 segmented flow analyzer with low-level nutrient capability
- Fisher Scientific Marathon 3200 centrifuge

Metals Analytical Instrumentation

- Varian AA-1475 atomic absorption spectrophotometer
- Perkin Elmer 4100ZL atomic absorption spectrophotometer (2)
- Lachat Quick Chem Model 8000 Atomic Fluorescence Mercury Analyzer
- Leeman Labs Hydra AF Gold+ Atomic Fluorescence Mercury Analyzer
- Varian 720 ICP-OES
- Thermo Jarrel Ash 61E Trace ICP
- Varian 820 ICP-MS

Volatile Organics Instrumentation (GC, GC-MS)

- Varian 3400-CX GC with FID/PID (GRO/PVOC)
- Varian 3400 GC with FID (methanol)
- Varian 3400 GC FID (Volatile Fatty Acids)
- Varian 3400 GC FID (Methane, Ethane, Ethene)
- Varian 2000 GC/MS
- Varian Saturn 2 GC/MS (VOC's)
- Varian Saturn 3 GC/MS (SDWA VOC's)
- Varian Saturn 3900/2100D GC/MS (SDWA VOC's)
- Tekmar LSC 2000 Purge and Trap with ALS 2016 16 position autosampler (2)
- Tekmar LSC 3000 Purge and Trap with ALS 2016 16 position autosampler (3)
- Tekmar/Teledyne Atomix Purge and Trap Auto Sampler

Semi-volatile Organic Instrumentation (GC, GC-MS)

- Hewlett Packard 5890 with dual ECD (552 HAA's)
- Hewlett Packard 5890 Series II GC/MS (8270)
- Varian Saturn 3800/2000R-1 GC/MS (527 Flame Retardants)
- Varian Saturn 3800/2000R-2 GC/MS (525 SOC's, 548 Endothal)
- Varian Saturn 3800/2200-1 GC/MS/MS (521 Nitrosamines)
- Varian Saturn 3800/2200-2 GC/MS/MS (529 Explosives)

Organic Instrumentation (pesticides/PCB's)

- Hewlett Packard 5890 Series II GC with dual ECD (8081/8082 Chlorinated Pest/PCB's)
- Hewlett Packard 5890A GC with dual NPD (8141 NP Pesticides)
- Hewlett Packard 5890 Series II dual injector with ECD and FID (504/505 and DRO)

Semi-volatile Organic Instrumentation (liquid chromatography)

- Agilent / Hewlett Packard Series 1050 HPLC with diode array detector (549 diquat)
- Agilent / Hewlett Packard Series 1100 HPLC with Pickering PCX 5200 Post Column Derivatizer with fluorescence detector (531 Carbamates, 547 Glyphosate)
- Hewlett Packard 3D Win Chemstation for HPLC software
- Varian 1200 Quadrupole LC/MS/MS (535 breakdown pesticides)

On-site Analytical Gas Generator

- Parker Balston Nitrogen Generator with Atlas/Copco oil free industrial compressor

Field Sampling Equipment

- 2008 Chevrolet Express Van, equipped with mobile field laboratory
- 2011 Chevrolet Express Van, equipped with mobile field laboratory
- GeoTech Peristaltic pump (4)
- ISCO composite sampler with flow meter, and recording chart (2)
- Oakton Model II pH meter (4)
- Oakton model 110 pH meter
- Orion model 920A multi-purpose pH/ISE meter
- Testwell Water Level Meter 300 foot
- VWR model 2052 conductivity meter (4)
- Grundfos Redi-Flo2 environmental pump
- Honda model EG2500 portable generator
- RKI Eagle Methane and Oxygen Meter
- 2009 Trinity 5 x 10 aluminum trailer
- VWR Traceable digital thermometer (2)
- Hanna Traceable digital thermometer (2)
- Hanna HI9828 pH, ORP, EC, DO field meter
- 1.5 inch Semi-trash pump

- Proactive Hurricane PVL pump
- Proactive Tsunami PVL pump (2)
- Proactive Mega Tsunami PVL pump
- Proactive Power Booster II Controller
- Solinst water level meter, 200 foot
- Solinst coaxial water level meter, 200 foot
- Solinst water level meter, 100 foot

10.2 Documentation and Labeling of Standards and Reagents

All analytical reagents, standards, and quality control materials are ordered from reliable, reputable sources (i.e. APG, ERA, Protocol). Incoming reagents and standards are labeled with a received date and an opened date. Records of source, purity, traceability, etc are retained or recorded by the user. MSDS are received and filed by the safety committee for each chemical / reagent used. Prepared reagents and standards are labeled appropriately and preparation is documented in the appropriate logbook. All reagents and standards are isolated from samples. They are stored in small refrigerators or freezers near their point of use. Temperature and condition of these storage devices is monitored and recorded. All reagents and standards are discarded prior to the expiration date.

10.3 Computers and Electronic Data Related Requirements

The following is from the introductory materials for the LIMS SOP. Refer to that document for more specific detail:

The NLS Laboratory Information System is a custom built database running on the Oracle 11gR2 database system. The database is running on a custom-built dual-quadcore Intel Xeon Server using the SuSE Linux Enterprise Server OS version 11 provided by Novell. All operating procedures for the SuSE 11 operating system can be referenced in the SuSE11 Documentation Set, and should only be performed by an experienced UNIX System Administrator. The Oracle 11gR2 database maintenance procedures are referenced in the Oracle RDBMS 11gR2 Documentation Set, and should only be performed by a skilled Database Administrator.

10.4 Preventative Maintenance

Scheduled maintenance is performed on all analytical equipment. Maintenance procedures for individual instruments are performed according to instructions in the specific owner and operation manual for that piece of equipment. All operation manuals are maintained near each instrument and readily available to each analyst/chemist.

Each chemist/analyst maintains an inventory of parts and supplies per manual/manufacture recommendation to minimize work delays in the case of equipment failure. This inventory not only includes smaller incidental parts such as tubing, bulbs, columns, etc, but also larger items such as sampling towers, pumps, computer boards and autosamplers for certain pieces of equipment. NLS also retains instruments that have been removed from service that may be used for parts when necessary.

Refrigerators are monitored daily for temperature; the temperature is kept at 1-6 degrees C. The large walk-in refrigerator is continually monitored by computerized sensors and is alarmed to the homes of computer operations staff. The BOD-5 incubator is kept at 20 ± 1 degrees C, and temperature is monitored daily.

Analytical balances are cleaned frequently and serviced and calibrated annually by E&B Scale. Balances are checked with class S weights when they are used.

Conductivity, pH, and specific ion electrodes are rinsed with reagent grade water after each use. Probes are also cleaned according to cleaning procedure in operation manuals. Records outlining daily measurements are kept for a minimum of five years. The following list outlines the type of measurements recorded:

1. Sample storage refrigeration temperatures.
2. Standards storage refrigeration temperatures.
3. Laboratory oven temperatures.
4. Laboratory digestion block temperatures.
5. Standardization of pH and conductivity meters.
6. Water bath systems temperatures.
7. Turbidity meter calibration.
8. Conductivity of reagent grade water.

9. Standardization of field meters.
10. pH of preserved samples.
11. Calibration of laboratory thermometers.
12. Sample extraction data and procedures.
13. Sources and lot numbers of standards used.
14. Maintenance logs for analytical instruments.
15. Analytical instrument run logs.
16. Records of computer archived raw data.
17. Room temperatures for TCLP/SPLP leaching tests.

A maintenance and troubleshooting log is maintained for each analytical instrument. Routine maintenance is defined by NLS as any activity taking place on at least a weekly basis. Routine maintenance is laid out in each individual SOP and is not generally documented in the maintenance log. Procedures not defined and carried out as routine are noted in the log. The five-step process outlined in section 12 of this document is used in resolving maintenance/troubleshooting issues.

10.5 Inspection / Acceptance Requirements for Supplies and Consumables

All incoming supplies and consumables are visually inspected immediately upon receipt. They are then opened, unpacked, inspected and delivered to the appropriate staff member by the purchasing agent. If damage to the product is noted, the vendor is immediately contacted and the product is returned or discarded per their instructions. Date of receipt is recorded on each bottle. Standards used for calibration or verification, and any supplies, reagents, or specific chemicals used for sample preparation or analysis are purchased from reputable sources. These items are verified as being suitable for use through routine method QA/QC measures, historical performance of the materials and suppliers, external certifications or standards with which the supplier adheres to, or internal evaluation by the laboratory.

11.0 SPECIFIC ROUTINE PROCEDURES USED TO EVALUATE DATA QUALITY

11.1 LABORATORY QUALITY CONTROL LIMITS

In industrial applications, control limits are recommended for each product, each machine, and each operator. In the laboratory environment, the parameter of interest, the instrument, and the operator are analogous system variables. However, environmental laboratories routinely have to contend with a variable that has no industrial counterpart - the true concentration level of the parameter of interest, which may vary considerably among samples. Unfortunately, the statistics that work well in industrial applications are sensitive to the variability in true concentration that is found in environmental analysis. This variability in true concentration means that there are no expected values for randomly selected samples, so that the accuracy of testing methodology must be evaluated indirectly through the recovery of known standards and spikes. As a result, it is somewhat difficult to apply industrial quality control techniques to the environmental laboratory.

11.2 Accuracy Control Limits

Accuracy is defined as the ability to obtain a result with minimal deviation from the actual amount. Control limits for accuracy are calculated after running a minimum of thirty analyses on spiked samples. The accuracy of the analysis is recorded as percent recovery. Percent recovery (P) can be calculated using the following equation:

$$P = \frac{(\text{observed result} - \text{background})}{(\text{amount of spike})} \times 100\%$$

After collecting a minimum of thirty data points for percent recovery, the average percent recovery (P_a) is calculated using the following equation:

$$P_a = \frac{\Sigma P}{(\text{number of points})}$$

The standard deviation (P_s) is calculated using the following equation:

$$(P_s) = \sqrt{[\Sigma (X_i - X_{\text{avg}})^2 / (n-1)]} \quad \text{where } n = \text{number of points}$$

The warning and control limits are calculated using the following equations:

$$\begin{aligned} \text{Upper Control Limit} &= \text{UCL} = P_a + 3(P_s) \\ \text{Upper Warning Limit} &= \text{UWL} = P_a + 2(P_s) \\ \text{Lower Warning Limit} &= \text{LWL} = P_a - 2(P_s) \\ \text{Lower Control Limit} &= \text{LCL} = P_a - 3(P_s) \end{aligned}$$

During an analytical run, every one out of ten samples are spiked and analyzed.

Precision Control Limits

Precision is defined as the ability to obtain the same result every time a sample is analyzed. Control limits for precision are calculated after a minimum of thirty analyses on duplicate samples. Results of duplicate sample analyses, duplicate spike analyses, and/or duplicate sample analyses can be used to determine precision within each batch. The relative percent difference (RPD) between the two duplicates is evaluated against control limits established for the analyte. The RPD is

calculated as follows:

$$\text{Relative \% Difference} = \frac{|D1 - D2|}{(D1 + D2) / 2} * 100$$

D1 = Result of first duplicate

D2 = Result of second duplicate

Unless otherwise specified by the analytical method, associated reference guidance, or client-specific project plan, the RPD between spiked samples will be calculated using the absolute values of their measured concentrations, and not the values of their percent recoveries.

Unless otherwise specified, control limits for RPD are based upon representative mid-level responses. For most methods performed in the laboratory, RPD values will increase dramatically as the absolute values of the replicates approach the LOD or MRL. Necessity for corrective action will not, therefore, be indicated when low concentration replicates (i.e., one or both replicates less than 5 times the MRL) yield an RPD value above the control limit.

During an analytical run, one out of ten samples are run in duplicate. Many of these duplicate analyses involve the spiking of the samples to provide a non-zero result.

11.3 Surrogate Recoveries

Surrogate recoveries for methods where required are monitored daily for compliance with method or in-house limits and regularly used to recalculate in-house limits.

11.4 Method Blanks

Method blanks are analyzed with every analytical batch. If a method blank is found to have a concentration of the target analyte above the method detection limit, the analytical batch associated with it is re-analyzed or, if reanalysis is not possible or practical, the data is qualified. In some cases, specifically certain metals analyses, data is used if the concentration in the blank is above MDL but below several specified limits (i.e. WI NR 149 criteria)

12.0 Corrective Action

Corrective actions are a vital part of NLS' continuing quality improvement strategy. Corrective actions are found in specific SOPs and also in the "Northern Lake Service, Inc. QC Failure Corrective Actions and Data Review Plan" document. Copies of this document are kept by the supervisors, the Laboratory Manager and in other production areas and are made available to staff for use when corrective actions are required.

When a deviation from standard operating procedures and/or method requirements occurs, whether it be due to specific client request, quality control failure or any other reason within or outside of our control the anomaly is recorded on a "Northern Lake Service Continuous Quality Improvement Anomaly / Incident Report". This report documents the issue, the clients affected and the actions taken. The chemist / analyst, with the assistance of the Laboratory Manager and/or supervisor if appropriate and/or necessary, is responsible for making and documenting the appropriate corrective action. The QA Officer is responsible for ensuring completion of the corrective action and documentation of completion. The QA Officer retains completed reports.

Corrective actions whether in response to quality control failures, instrument maintenance issues, or cited internal or external audit deficiencies, will be dealt with using the following 5-step model:

1. Identify the problem
2. Determine the root cause
3. Develop the corrective action plan
4. Implement the plan
5. Document return to acceptable conditions

13.0 SUBCONTRACTING AND SUPPORT SERVICES

13.1 Northern Lake Service, Inc. makes every effort to keep subcontracted laboratory work to a minimum. As a result, the percentage of work performed for NLS by other laboratories is very low. Subcontract laboratories are chosen based upon certification, data quality objectives and price. The Client Service Department maintains a file of certified laboratories, and a database of other potential subcontract laboratories. Occasionally clients request a specific subcontract laboratory be used; otherwise, NLS client-service staff will determine the appropriate laboratory for a given analysis. The receiving department maintains a sub-contract list with specific parameter information. This list is updated as needed. Subcontracted data is reviewed by the Client Service Department or other designated staff during LIMS entry, and again at final report review.

13.2 Outside Services and Supplies

- A) Consumables –Standards used for calibration or verification, and any supplies, reagents, or specific chemicals used for sample preparation or analysis are purchased from reputable sources. These items are verified as being suitable for use through routine method QA/QC measures, historical performance of the materials and suppliers, external certifications or standards with which the supplier adheres to, or internal evaluation by the laboratory.
- B) Courier service – NLS utilizes several bonded commercial courier services for sample delivery. Couriers are aware of time and temperature constraints required in our industry. If these requirements are not adhered to, the courier is contacted so that corrections can be made.
- C) Gases – in order to maintain quality and dependability, NLS maintains a contract with a nationwide distributor of specialty gases. Argon is stored in a bulk tank on-site and all other bottled gases are received as needed through weekly delivery.
- D) HVAC – Heating, cooling and ventilation systems are maintained cooperatively between NLS staff and licensed, commercial HVAC specialists. These specialists are highly aware of the required operating conditions of our facility.
- E) Waste – Non-hazardous, consumer-type waste and standard recyclables are separated and disposed of through a reputable, national solid-waste disposal company. All hazardous waste is appropriately store and periodically disposed of through an appropriately licensed hauler. Materials documenting this procedure are maintained by the Quality Control Officer, are periodically inspected by a state regulatory authority, and managed under the guidelines of *Very Small Quantity Generator* status. Paper waste containing confidential information is periodically disposed of through a reputable service. The Quality Control Officer maintains documents of destruction.

14.0 REFERENCES

Northern Lake Service, Inc. uses the following resources for analytical, quality control, and preservation guidelines:

1. American Public Health Association, et. al. Standard Methods for the Examination of Water and Wastewater. 16th -20th Editions. American Public Health Association. Washington, D.C.
2. American Society of Testing and Materials, 1995-1999. Annual Book of ASTM Standards - Water and Environmental Technology, Section 11, volume 11.01 - 11.05; ASTM, Philadelphia, PA.
3. American Society of Agronomy, et. al. 1982. Methods of Soil Analysis Part 2 - Chemical and Microbiological Properties. 2nd Edition. Edited by A.L. Page, R.H. Miller, D.R. Keeney. Soil Science Society of American. Madison, Wisconsin.
4. Code of Federal Regulations, Guidelines Establishing Test Procedures for the Analysis of Pollutants Under the Clean Water Act. Final Rule; Title 40, Part 136. Government Printing Office. Washington D.C.
5. Code of Federal Regulations, National Primary Drinking Water Regulations. Final Rule; Title 40, Part 141. Government Printing Office. Washington D.C.
6. Perkin-Elmer. Analytical Methods for Atomic Absorption. 1982 and Updates. Perkin-Elmer Corporation.
7. Technicon Industrial Systems. Technicon Autoanalyzer II Operation Manual. Technicon Instrument Corporation. Tarrytown, New York.
8. United States Environmental Protection Agency, Methods for the Determination of Metals in Environmental Samples. June, 1992. EPA/600/4-91/010. Supplement 1, May 1994. EPA/600/R-91/111.
9. United States Environmental Protection Agency. Handbook for Analytical Quality Control in Water and Wastewater Laboratories. March 1979. EPA-600/4-79-019. Revised 1983.
10. United States Environmental Protection Agency. Methods for the Chemical Analysis of Water and Wastes. March, 1983. EPA-600-4-79-020. Government Printing Office. Washington, D.C.
11. United States Environmental Protection Agency. Methods for Organic Analyses of Municipal and Industrial Wastewater. July 1982. EPA-600/4-82-057. Government Printing Office. Washington, D.C.
12. United States Environmental Protection Agency. Test Methods for Evaluating Solid Waste. July 1982. SW-846. Third Edition and Updates I, II, III and IIIA. Government Printing Office. Washington, D.C.
13. United States Environmental Protection Agency. Methods for the Determination of Organic Compounds in Drinking Water. December 1988. EPA-600/4-88-039, plus Supplements 1 & 2.
14. United States Environmental Protection Agency. Technical Notes on Drinking Water. October 1994. EPA/600/4-94/173.
15. Varian Techtron Pty. LTD. Analytical Methods for Flame Spectroscopy. Varian Techtron, Springvale, Australia.
16. Varian Inc. Techniques of Simultaneous ICP-OES 700-ES Series. Version 6.0, October 2007. Prepared by Dr. Hilton Greenburg.
17. United States Environmental Protection Agency. Methods for the Determination of Inorganic Substances in Environmental Samples. August 1993. EPA-600/R-93/100.

18. Dionex Corporation. GP50 Gradient Pump Operators Manual. Revision 01, May 1998. Sunnyvale, California.
19. Dionex Corporation. CD20 Conductivity Detector Operators Manual. Revision 03, February 1996. Sunnyvale, California.
20. Astoria - Pacific International. Astoria 2 Analyzer Operation Manual. 2008. Astoria - Pacific, Inc. Clackamas, Washington.
21. Varian, Inc. Varian 810/820 ICP-MS Customer Training Manual. June 2006. Prepared by Andrew Toms.
22. National Environmental Laboratory Accreditation Conference. 2003 NELAC Standard. June 2003. EPA/600/R-04/003.
23. The NELAC Institute. Environmental Laboratory Sector, TNI Standard. EL-V1-2011.

APPENDICES

APPENDIX – A

Procedure for Demonstration of Capability

- A. A demonstration of capability (DOC) must be made prior to using any test method, and at any time there is a significant change in instrument type, personnel or test method.
 1. “Significant change” refers to any change in personnel, instrumentation, test method, or sample matrix that potentially impacts the precision, accuracy, sensitivity, and selectivity of the output (for example, a change in the detector, or other components of the sample analytical system, or a method revision). All new analysts, regardless of experience on that instrument in another laboratory, shall complete a demonstration of capability.
- B. In general, this demonstration does not test the performance of the method in real world samples, but in the applicable and available clean matrix (a sample of a matrix in which no target analytes or interferences are present at concentrations that impact the results of a specific test method), e.g., water or solids. However, before any results are reported using this method, actual sample spike results may be used to meet this standard, i.e., at least four (4) consecutive matrix spikes within at least twelve months. In addition, for analytes, which do not lend themselves to spiking, e.g., TSS, the demonstration of capability may be performed using quality control samples.
- C. All demonstrations shall be documented through the use of the form in Appendix B.
- D. The following steps, which are adapted from the EPA test methods published in 40 CFR Part 136, Appendix A, shall be performed if required by mandatory test method or regulation.
 1. A quality control sample shall be obtained from an outside source. If not available, the QC sample may be prepared by the laboratory using stock standards that are prepared independently from those used in instrument calibration.
 2. The analyte(s) shall be diluted in a volume of clean matrix sufficient to prepare four (4) aliquots at the concentration specified, or if unspecified, to a concentration approximately 10 times the method-stated or laboratory-calculated method detection limit.
 3. At least four aliquots shall be prepared and analyzed according to the test method either concurrently or over a period of days.
 4. Using all the results, calculate the mean recovery (\bar{X}) in the appropriate reporting units (such as ug/L) and the standard deviations (s) of the population sample (n-1) in the same units, for each parameter of interest. When it is not possible to determine mean and standard deviations, such as for presence/absence values, the laboratory will assess performance against established and documented criteria.
 5. Compare the information from (4) above to the corresponding acceptance criteria for precision and accuracy in the test method (if applicable) or in laboratory-generated acceptance criteria (if there are no established mandatory criteria). If all parameters meet the acceptance criteria, the analysis of actual samples may begin. If any one of the parameters does not meet the acceptance criteria, the performance is unacceptable for that parameter.
 6. When one or more of the tested parameters fail at least one of the acceptance criteria, the analyst must proceed according to (a) or (b) below.

- a) Locate and correct the source of the problem and repeat the test for all parameters of interest beginning with (3) above.
- b) Beginning with (3) above, repeat the test for all parameters that failed to meet criteria. Repeated failure, however, will confirm a general problem with the measurement system. If this occurs, locate and correct the source of the problem and repeat the test for all compounds of interest beginning with (3).

Northern Lake Service, Inc.

Method Capability Certification Statement

- A. The laboratory must document the method capability certification of its analysts.
- B. All training is documented through the use of “Employee Method Training Verification Forms” prior to the analyst performing analyses on client compliance samples. The above listed training verification form includes the following ten (10) items.
1. Employee has read and understands the test method.
 2. Employee has read all appropriate SOPs.
 3. Employee knows and understands all safety procedures.
 4. Employee understands the sample handling / documentation system.
 5. Employee understands the Quality Control requirements / procedures for: (Reagents, Bench sheets / Paperwork, Instrument Logs, Lab Notebooks, Spike Mixes, Spike / Duplicate / Lab Control Sample analysis).
 6. Employee has observed the method performed by a qualified staff member.
 7. Employee has assisted a qualified staff member perform the test method.
 8. Employee has performed the test method under supervision.
 9. Employee has successfully performed the test method upon a Blind / Performance Evaluation Sample.
 10. Employee has performed the Initial Demonstration of Accuracy and Precision.
- C. The analyst must document the performance of an acceptable Demonstration of Capability study for each analytical method. This documentation is attested to using the “Demonstration of Capability Certification Statement”. The four (4) points shown on this form are as follows:
1. The analyst identified above, using the cited test method, which is in use at this facility for the analysis of samples under the Wisconsin Department of Natural Resources, USEPA, or other project specific programs, has met the Demonstration of Capability.
 2. The analyst identified on the certificate form performed the test method.
 3. A copy of the test method and the laboratory-specific SOP are available for all personnel on-site.
 4. The data associated with the demonstration of capability, if applicable, are true, accurate, complete and self-explanatory.
 - a) True: Consistent with supporting data.
 - b) Accurate: Based on good laboratory practices consistent with sound scientific principals / practices.
 - c) Complete: Includes the results of all supporting performance testing.
 - d) Self-explanatory: Data properly labeled and stored so that the results are clear and require no additional explanation.
 5. All raw data (including a copy of this certification form) necessary to reconstruct and validate these analyses have been retained at Northern Lake Service, and that the associated information is well-organized and available for review by authorized assessors, if applicable.
- D. The analysts at Northern Lake Service must certify that they have read their Official Standard Operating Procedures and agree that they are accurate and acceptable for their use as well as attesting that they have shown Continued Proficiency in their analyses of Blind and Performance Evaluation samples. Shown below are the items that are certified by the analyst and their supervisor.
1. I have read and understood the following Northern Lake Service – “Official” Standard Operating Procedures and agree that they are accurate and acceptable for my use.
 2. I also attest to the fact that I have performed the listed procedures and have shown documented “Continued Proficiency” at least once per year through one or more of the following:
 - a) Acceptable performance of Blind QC Samples
 - b) Another Demonstration of Capability
 - c) Acceptable analysis of a Blind – Performance Evaluation Sample
 - d) At least four consecutive lab control samples with acceptable levels of precision and accuracy.

- E. In addition to the above-listed training, on-going method capability is demonstrated through the satisfactory completion of performance evaluation samples in national wastewater, drinking water and soil analysis studies.
- F. Method capability certification is also demonstrated through participation in internal and external technical audits.
- G. Performance evaluation sample performance results are documented in reports of the national studies and are maintained in the Quality Assurance Officer's office and the analyst's training file. The QA Officer keeps audit findings on file.
- H. Attached are copies of the following Northern Lake Service "Method Capability Certification" forms:
 - 1. Employee Method Training Verification Form
 - 2. Demonstration of Capability Certification Statement

NORTHERN LAKE SERVICE, INC.
EMPLOYEE METHOD TRAINING VERIFICATION FORM

Employee:

Method Name / Number:

VERIFICATION ITEM	YES	NO	COMMENTS
1. Employee has read and understands the test method.			
2. Employee has read all appropriate SOPs.			
3. Employee knows and understands all safety procedures.			
4. Employee understands the sample handling / documentation system.			
5. Employee understand the Quality Control requirements / procedures for: (Reagents, Bench sheets / Paperwork, Instrument Logs, Lab Notebooks, Spike Mixes, Spike / Duplicate / Lab Control Sample analysis).			
6. Employee has observed the method performed by a qualified staff member.			
7. Employee has assisted a qualified staff member perform the test method.			
8. Employee has performed the test method under supervision.			
9. Employee has successfully performed the test method upon a Blind / Performance Evaluation Sample.			
10. Employee has performed the Initial Demonstration of Accuracy & Precision.			

BLIND / PERFORMANCE EVALUATION SAMPLE RESULTS (if applicable)

QC SAMPLE ID	PARAMETER	TRUE VALUE	MEASURED VALUE	% RECOVERY	ACCEPTABLE (Y/N)

I certify that I have received the training necessary to properly perform the test method indicated above.

Analyst

Date

I certify that, in my opinion and to the best of my knowledge, the above stated employee has been trained in a manner to assure that the data generated by this employee in the performance of this test method will meet the requirements of the projects that his/her job may require him/her to perform. I therefore certify that the employee is qualified to perform the above listed method within our laboratory based upon the employee's education, knowledge, technical training, and experience.

Instructor

Date

Supervisor

Date

NORTHERN LAKE SERVICE, INC.
400 North Lake Ave.
Crandon, WI 54520

***Demonstration of Capability
Certification Statement***

Date:	Analyst Name:
Matrix:	Reference Method Number:
Analyte / Compounds:	NLS SOP Number:

We, the undersigned, CERTIFY that:

- The analyst(s) identified above, using the cited test method(s), which is in use at this facility for the analyses of samples under the National Environmental Laboratory Accreditation Program, as well as other programs, have met the Demonstration of Capability.*
 - ☐ *Initial Demonstration of Capability (IDC) is not required as per Section (10.2.1) paragraph c.) of the DoD Quality Systems Manual – Final Version 2, June 2002. Analyst was performing the method prior to July, 1999.*
- The test method(s) was performed by the analyst(s) identified on this certification form.*
- A copy of the test method(s) and the laboratory-specific SOP(s) are available for all personnel on-site.*
- The data associated with the demonstration capability, if applicable, are true, accurate, complete and self-explanatory. **
- All raw data (including a copy of this certification form) necessary to reconstruct and validate these analyses have been retained at Northern Lake Service, and that the associated information is well organized and available for review by authorized assessors, if applicable.*

Technical Director's Name:	Signature:	Date:
Title:		
Quality Assurance Officer's Name:	Signature:	Date:

- * True: Consistent with supporting data.
Accurate: Based on good laboratory practices consistent with sound scientific principles / practices.
Complete: Includes the results of all supporting performance testing.
Self-explanatory: Data properly labeled and stored so that the results are clear and require no additional explanation.

NLS Internal Audit Checklist - Example

Date: Department: Audit No:

Analyst: Instrument: Methods:

- EPA / Standard Methods Methodology available:
- NLS – SOP current and meets NLS requirements:
- QC Limits available and recorded:
- LCS Information used and recorded:
- Calibration shows calibration curve data and requirements:
- Instrument Maintenance Log used and current:
- Maintenance or Problem – Corrective Action in Narrative Form:
- “Return to Control” (Closing the Loop) is noted in Maintenance Log for problems:
- Method Detection Limits Current and Verified:
- Initial Demonstration of Capability have been performed and data are available:
- Acceptance Criteria for Monitoring Instrument Operation are used:
- QC Failure Procedure Protocol is written and is current:
- Reagent and Standards Preparation Log current and complete:
- Quality Data Verification (Review) Checklist is Written and Complete:
(Calibration, Quality Control, Error Checks, Holding Times, Data Entry Verified, Peer Reviewed)

Northern Lake Service
Final Report Format - Example

Northern Lake Service, Inc.

Essential Quality Control Requirements

- A. The quality control protocols specified by the laboratory's method manual shall be followed. The laboratory shall ensure that the essential standards outlined in this Appendix F are incorporated into their method manuals.
- B. All quality control measurements shall be assessed and evaluated on an ongoing basis and quality control acceptance criteria shall be used to determine the validity of the data. The laboratory shall have procedures for the development of acceptance / rejection criteria where no method or regulatory criteria exists.
- C. The requirements from the following section apply to all types of testing. The specific manner in which they are implemented is detailed in each of the sections of this Appendix, i.e., Chemical Testing, Microbiological Testing.
- D. Quality Control – Corrective Action: When quality control measures fail the acceptance criteria specified in these requirements, corrective action shall be taken. Different corrective responses may be appropriate in different situations, based on project-specific requirements and the magnitude of the problem. Examples of corrective actions include:
- Determining the source of the problem,
 - Notifying the client,
 - Reprocessing samples,
 - Using data qualifiers to “flag” data, and
 - Adding commentary in laboratory reports
- E. All laboratories shall have detailed written protocols in place to monitor the following quality controls:
- 1) Positive and negative controls to monitor tests such as blanks, spikes, reference samples;
 - 2) Tests to define the variability and / or repeatability of the laboratory results such as replicates;
 - 3) Measures to assure the accuracy of the test method including calibration and / or continuing calibrations, use of certified reference materials, proficiency test samples, or other measures;
 - 4) Measures to evaluate test method capability, such as detection limits and quantitation limits or range of applicability such as linearity.
 - 5) Selection of appropriate formulae to reduce raw data to final results such as regression analysis, comparison to internal / external standard calculations, and statistical analyses;
 - 6) Selection and use of reagents and standards of appropriate quality;
 - 7) Measures that assure the selectivity of the test for its intended purpose;
 - 8) Measures to assure constant and consistent test conditions (both instrumental and environmental) where required by the test method, such as temperature, humidity, light, or specific instrument conditions.
- F. All quality control measures shall be assessed and evaluated on an on-going basis, and quality control acceptance criteria shall be used to determine the usability of the data.
- G. The laboratory shall have procedures for the development of acceptance / rejection criteria where no method or regulatory criteria exist.
- H. The quality control protocols specified by the laboratory's method manual shall be followed. The laboratory shall ensure that the essential standards outlined in this Appendix F, or mandated methods or regulations (whichever are more stringent) are incorporated into their method manuals. When it is not apparent which is more stringent the QC in the mandated method or regulations is to be followed.

Chemical Testing

A. Negative Controls

- 1) Method Blanks – shall be performed at a frequency of one per preparation batch of samples per matrix type. The results of this analysis shall be one of the QC measures to be used to assess the batch. The source of contamination must be investigated and measures taken to correct, minimize or eliminate the problem if
 - i. the blank contamination exceeds a concentration greater than 1/10 of the measured concentration of any sample in the associated sample batch or
 - ii. the blank contamination exceeds the concentration present in the samples and is greater than 1/10 of the specified regulatory limit.
- 2) Any sample associated with the contaminated blank shall be reprocessed for analysis or the results reported with appropriate data qualifying codes or comments.

B. Positive Controls:

- 1) Laboratory Control Sample (LCS) – (QC Check Samples) Shall be analyzed at a minimum of 1 per preparation batch of 20 or less samples per matrix type, except for analytes for which spiking solutions are not available such as total suspended solids, total dissolved solids, total volatile solids, total solids, pH, color, odor, temperature, dissolved oxygen or turbidity. The results of these samples shall be used to assess the batch. Note: The matrix spike may be used in place of this control as long as the acceptance criteria are as stringent as for the LCS.
- 2) Matrix Spikes (MS) – Shall be performed at a frequency of one out of every 20 samples per matrix type prepared over time, except for analytes for which spiking solutions are not available such as, total suspended solids, total dissolved solids, total volatile solids, total solids, pH, color, odor, temperature, dissolved oxygen or turbidity. The selected sample(s) shall be rotated among client samples so that various matrix problems may be noted and / or addressed. Poor performance in a matrix spike may indicate a problem with the sample composition and shall be reported to the client whose sample was used for the spike.
- 3) Surrogates – surrogate compounds must be added to all samples, standards, and blanks, for all organic chromatography methods except when the matrix precludes its use or when a surrogate is not available. Poor surrogate recovery may indicate a problem with the sample composition and shall be reported to the client whose sample produced the poor recovery.
- 4) If the mandated or requested test method does not specify the spiking components, the laboratory shall spike all reportable components to be reported in the Laboratory Control Sample and Matrix Spike. However, in cases where the components interfere with accurate assessment (such as simultaneously spiking chlordane, toxaphene, and PCBs in Method 608), the test method has an extremely long list of components or components are incompatible, a representative number (at a minimum 10%) of the listed components may be used to control the test method. The selected components of each spiking mix shall represent all chemistries, elution patterns and masses, permit-specified analytes, and other client-requested components. However, the laboratory shall ensure that all reported components are used in the spike mixture within a two-year time period.

- C. Analytical Variability / Reproducibility: Matrix Spike Duplicates (MSDs) or Laboratory Duplicates – shall be analyzed at a minimum of 1 in 20 samples per matrix type per sample extraction or preparation method. The laboratory shall document its procedure to select the use of appropriate type of duplicate. The selected

- D. Sample(s) shall be rotated among client samples so that various matrix problems may be noted and / or addressed. Poor performance in duplicates may indicate a problem with the sample composition and shall be reported to the client whose sample was used for the duplicate.
- E. Method Evaluation – In order to ensure the accuracy of the reported results, the following procedures shall be in place:
- 1) Demonstration of Analytical Capability – The procedure shown in Appendix B of this document shall be performed initially (prior to the analysis of any samples) and with a significant change in instrument type, matrix or test method.
 - 2) Calibration – Calibration protocols specified in Section 5 of this document shall be followed.
 - 3) Proficiency Test Samples – The results of such analyses shall be used by the laboratory to evaluate the ability of the laboratory to produce accurate data.
- F. Detection Limits – the laboratory shall utilize a test method that provides a detection limit that is appropriate and relevant for the intended use of the data. Detection limits shall be determined by the protocol in the mandated test method or applicable regulation, e.g. Method Detection Limit (MDL). If the protocol for determining detection limits is not specified, the selection of the procedure must reflect instrument limitations and the intended application of the test method.
- 1) The detection limit study is not required for any component for which spiking solutions or quality control samples are not available such as temperature.
 - 2) The detection limit shall be initially determined for the compounds of interest in each test method in a matrix in which there are not target analytes or interferences at a concentration that would impact the results or the detection limit must be determined in the matrix of interest.
 - 3) Detection limits must be determined each time there is a change in the test method that affects how the test is performed, or when a change in instrumentation occurs that affects the sensitivity of the analysis.
 - 4) All sample processing steps of the analytical method shall be included in the determination of the detection limit.
 - 5) All procedures used must be documented. Documentation must include the matrix type. All supporting data must be retained.
 - 6) The laboratory must establish procedures to relate detection limits with quantitation limits.
 - 7) The test method's quantitation limits must be established and must be above the detection limits.
- G. Data Reduction: The procedures for data reduction, such as the use of linear regression, shall be documented.
- H. Quality of Standards and Reagents: The source of standards shall comply with Section 5.1 of this document.
- I. Reagent Quality: In methods where the purity of reagents is not specified, analytical reagent grade shall be used. Reagents of lesser purity than those specified by the test method shall not be used. The labels on the container should be checked to verify that the purity of the reagents meets the requirements of the particular test method. Such information shall be documented.
- J. Water: The quality of water sources shall be monitored and documented and shall meet method specified requirements.

- K. The laboratory will verify the concentration of titrants in accordance with written laboratory procedures.
- L. Selectivity: Absolute retention time and relative retention time aid in the identification of components in chromatographic analyses and to evaluate the effectiveness of a column to separate constituents.
- M. A confirmation shall be performed to verify the compound identification when positive results are detected on a sample from a location that has not been previously tested by the laboratory. Such confirmations shall be performed on organic tests such as pesticides, herbicides, or acid extractables, or when recommended by the analytical test method except when the analysis involves the use of a mass spectrometer. Confirmation is required unless stipulated in writing by the client. All confirmation shall be documented.
- N. The laboratory shall document acceptable criteria for mass spectral tuning.
- O. Constant and Consistent Test Conditions: The laboratory shall assure that the test instruments consistently operate within the specifications required of the application for which the equipment is used.
- P. Glassware cleaning – Glassware shall be cleaned to meet the sensitivity of the test method. Any cleaning and storage procedures that are not specified by the test method shall be documented in laboratory records and SOPs.

Northern Lake Service
Data Package Review Form - Examples

525 QC REVIEW

Run Date: _____ Analyst: _____ Initial Review: _____ QC
Review: _____

Run Completeness

_____ Run log page (copy) _____ DFTPP/Breakdown Standard Pass _____ ICAL/CCAL OK
_____ IS/Fort Areas w/in limits _____ Surr Recoveries w/in limits _____ Lab Blank < MDL
_____ Extraction log (copy) _____ Quantit Results Reviewed _____ MS/MSD w/in limits
_____ LCS w/in limits _____ Samples analyzed w/in 12 hrs _____ Chromatography O

Data Entry – All results are reviewed

_____ All dilutions are correct _____ Analyte values are correct
_____ All surrogates are correct _____ Appropriate comments included

General

Date Oldest Sample Collected:

Date Samples Extracted:

Date Samples Analyzed:

Maximum holding time for 525 Extraction is 14 days for waters.

Maximum holding time for Instrument Analysis of extracts is 40 Days.

8310 QC REVIEW

Run Date: _____ Analyst: _____ Initial Review: _____ QC Review: _____

Run Completeness

_____ Run log page (copy) _____ Sequence Page from data station _____ Curve information
_____ Extraction log (copy) _____ Quantit Results Reviewed _____ MS w/in limits
_____ LCS/LCSD w/in limits _____ Continuing Cal w/in limits _____ Chromatography OK

Data Entry – All results are reviewed

_____ All dilutions are correct _____ Analyte values are correct
_____ All surrogates are correct _____ Appropriate comments included

General

Date Oldest Sample Collected:

Date Samples Extracted:

Date Samples Analyzed:

Maximum holding time for PAH Extraction is 7 days for waters.

Maximum holding time for Instrument Analysis of extracts is 40 Days.

8260/524.2 QC REVIEW

Run Date: _____ Analyst: _____ Initial Review: _____ QC Review: _____

Run Completeness

- _____ Run log page (completed)
- _____ BFB Standard Pass
- _____ Laboratory Blank values < MDL
- _____ Continuing Calibration Verification Recoveries w/in QC limits or qualified
- _____ Internal Standard Areas w/in limits
- _____ Surrogate Recoveries w/in QC limits or qualified
- _____ LCS Recoveries w/in QC limits or qualified
- _____ MS Recoveries w/in QC limits or qualified (8260 only)
- _____ MSD Duplicate Differences w/in QC limits or qualified (8260 only)

Comments:

Data Entry/Final Report – All sample results reviewed

- | | |
|--|----------------------------------|
| _____ All dilution factors are correct | _____ Analyte values are correct |
| _____ All surrogate values are correct
included | _____ Appropriate comments |

Comments:

General

- _____ Samples analyzed within 12-hour clock
- _____ Samples analyzed within required holding time (14 days for waters and 21 days for soils)

Additional Comments:

Northern Lake Service
Organizational Chart

Northern Lake Service, Inc – Organizational Chart

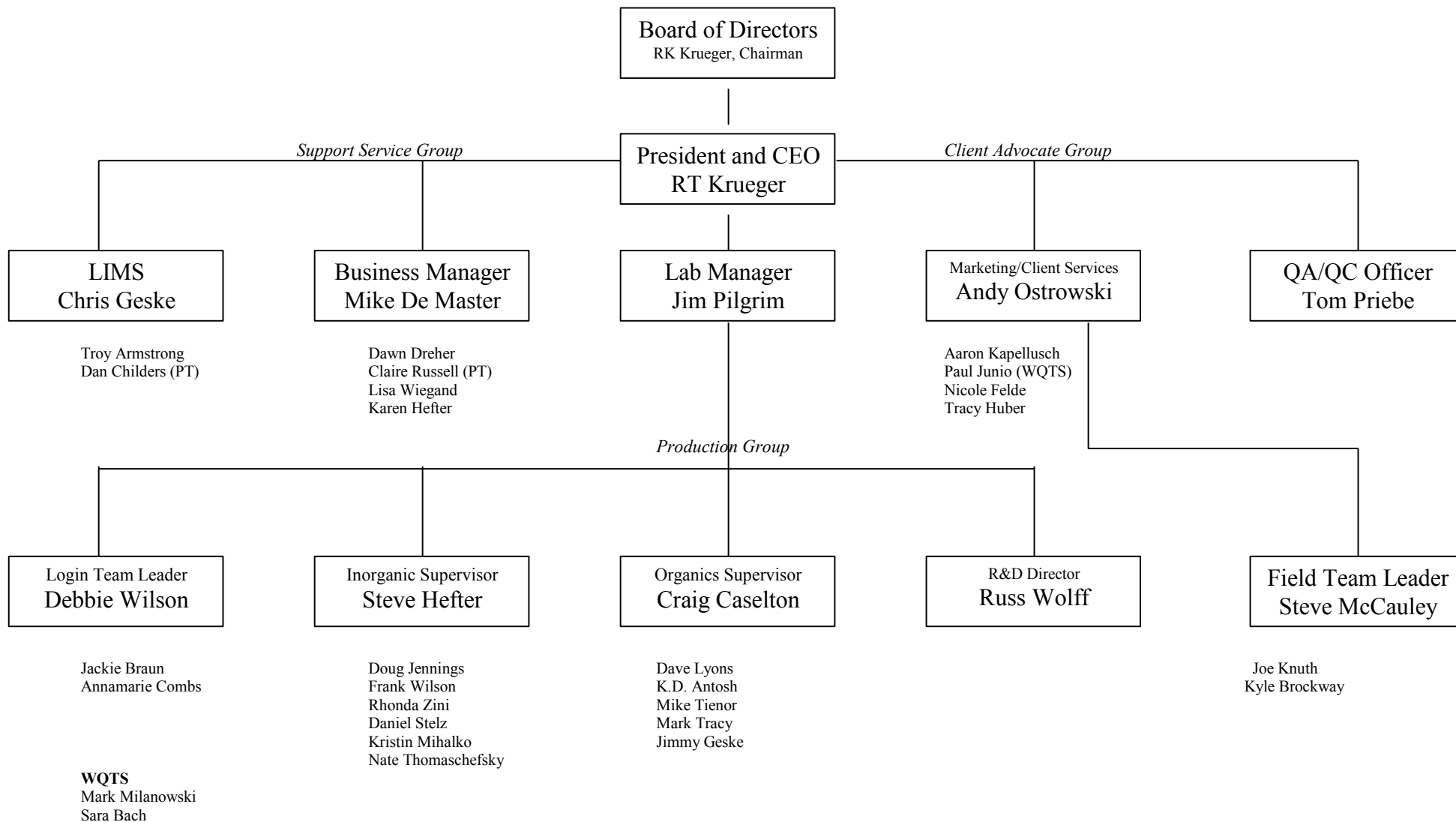


TABLE 2-1

Northern Lake Service, Inc. – Capabilities & Sample Handling

TEST/PARAMETER	CONTAINER	CONTAINER SIZE (mLs)	PRESERVATION	HOLD TIME
Alkalinity (Bicarb)	Plastic	125	NP, Cool 6°C	14 Days
Alkalinity (Total)	Plastic	125	NP, Cool 6°C	14 Days
Asbestos	Plastic	960	NP, Cool 6°C	48 Hrs
Atrazine (8141 Method)	Amber	2 (each) 1000	NP, Cool 6°C	7 Days to Extract
DW Atrazine	Amber	2 (each) 1000	HCL (chlorinated system HCL & Sodium Sulfite), Cool 6°C	14 Days
BOD	Plastic	500	NP, Cool 6°C	48 Hrs
Bromate	Plastic	125	50 mg/L EDA	28 Days
Bromide	Plastic	125	NP	28 Days
BTEX	Glass (VOC vial)	2 (each) 40	HCL, Cool 6°C	14 Days
CBOD	Plastic	250 Inf./500 Eff.	NP, Cool 6°C	48 Hrs
COD	Plastic	60	Sulfuric, Cool 6°C	28 Days
Chloride	Plastic	125	NP	28 Days
Chlorophyll	Plastic	960	NP, Filter, Freeze in Dark	28 Days
Chloroform	Glass	2 (each) 40	HCL, Cool 6°C	14 Days
Chromium (Hexavalent)	Plastic	250	NP, Cool 6°C	24 Hrs
Coliform (Fecal)	Plastic (sterile)	125	NP, Cool 6°C	24 Hrs
Coliform (Total)	Plastic	125	NP, Cool 6°C	24 Hrs
Chlorinated Well	(sealed)		NaThio for Chlor.	Extension (30)
Color	Plastic	125	NP, Cool 6°C	48 Hrs
Conductivity	Plastic	125	NP, Cool 6°C	28 Days
Cyanazine	Glass (Amber)	1000	NP, Cool 6°C	7 Days to Extraction
Cyanide (Amenable)	Plastic	250	NaOH (A), Cool 6°C, Store in Dark	14 Days
Cyanide (Total)	Plastic	250	NaOH (A), Cool 6°C, Store in Dark	14 Days
Cyanide (Solid)	Plastic	125	NP, Cool 6°C, Store in Dark	14 Days
Cyanide (Reactive)	Plastic	250	NP, Cool 6°C, Store in Dark	14 Days
DRO (Solid)	Glass (Soil Jar)	2 (each) 60 (Tared)	NP, Cool 6°C	10 Days to Extract
*DRO (Water)	Glass (Amber)	2 (each) 1000	HCL, Cool 6°C	7 Days
Dioxin	Amber	2 (each) 1000	NP, Cool 6°C	7 Days to Extraction
Endothall	Glass (Amber)	250	NaThio, Cool 6°C	7 Days
Formalin	Glass (Amber)	300	NP, Cool 6°C	7 Days
Flashpoint	Plastic	250	NP, Cool 6°C	14 Days
Fluoride	Plastic	125	NP	28 Days

TEST/PARAMETER	CONTAINER	CONTAINER SIZE (mLs)	PRESERVATION	HOLD TIME
Formaldehyde (DW-EHL)	Glass (Amber)	3 (each) 40 (vials)	Copper Sulfate & Ammonium Chloride, Cool 6°C	7 Days
Free Water	Plastic	125	NP, Cool 6°C	(NS)
GRO (Soil) or GRO/PVOC (Soil)	Glass (Soil Jar)	2 (each) 60 (Tared) Teflon cap	Methanol, Cool 6°C	21 days
GRO (Water)	Glass (VOC Vial)	2 (each) 40	HCl, Cool 6°C	14 Days
GRO / PVOC (Water)	Glass (VOC Vial)	2 (each) 40	HCl, Cool 6°C	14 Days
Haloacetic Acid (HAA)	Amber Glass	250	W/38 mg of ammonium chloride, Cool 6°C	7 Days
Hardness	Plastic	125	Nitric, Cool 6°C	6 Months
Ignitability (Solids)	Plastic	60	NP, Cool 6°C	28 Days
Lab Filtration	Plastic	960	NP, Cool 6°C	1 Day
Lab Filtration (TDS)	Plastic	125	NP, Cool 6°C	7 Days
Lead & Copper DW	Plastic	960	NP	14 Days to Add Nitric Acid at Lab (6 Months)
Mercury	Plastic	500	Nitric	28 Days
Mercury (Hg) (Low-Level)	Glass	250	NP	28 Days to add BrCl Preservative at Lab (28 days)
Mercury (Hg) Ultra Low Level + FB	Glass	250	NP	28 Days to add BrCl Preservative at Lab (28 days)
Metals w/o Hg	Plastic	250	Nitric	6 Months
Metals (Dissolved)	Plastic	250	Nitric, (Filter prior to Preservation)	6 Months
Metals DW comp. (Cu & Pb – SDWA)	Plastic	960	NP	14 Days to Add Nitric Acid at Lab (6 Months)
Metals DW N-comp	Plastic	960	Nitric	6 Months
Methane		2 (each) 40	HCL, Cool 6°C	14 Days
Methanol (Soil)	Amber (Glass)	1 (each) 60	NP, Cool 6°C	14 Days
Methanol		2 (each) 40	HCl, Cool 6°C	14 Days
Nitrate	Plastic	60	Sulfuric, Cool 6°C	28 Days
N as TKN (Water)	Plastic	60	Sulfuric, Cool 6°C	28 Days
N as TKN (Soil)	Plastic	60	NP, Cool 6°C	NS
N + N (Water)	Plastic	60	Sulfuric, Cool 6°C	28 Days (14 SDWA)
N + N (Solid)	Plastic	60	NP, Cool 6°C	NS
Nitrite (Water)	Plastic	125	NP, Cool 6°C	48 Hrs
Nitrite (Soil)	Plastic	60	NP, Cool 6°C	NS
N as Ammonia (Water)	Plastic	60	Sulfuric, Cool 6°C	28 Days
N as Ammonia (Solid)	Plastic	60	NP, Cool 6°C	NS
Nitrate (Water) corr.	Plastic	60	Sulfuric, Cool 6°C	28 Days
Nitrogen (Organic)	---	---	---	28 Days
Nitrogen (Total)	---	---	---	28 Days
Oil & Grease (Solid)	Glass	60	NP, Cool 6°C	28 Days
Oil & Grease (Water)	Glass	2 (each) 1000	HCl, Cool 6°C	28 Days
Oxygen, Dissolved		125	NP	Immediately
PAHs (Solid)	Glass	60	NP, Cool 6°C	14 Days to Extract

TEST/PARAMETER	CONTAINER	CONTAINER SIZE (mLs)	PRESERVATION	HOLD TIME
*PAHs (Water)	Glass (Amber)	2 (each) 1000 (Teflon cap)	NP, Cool 6°C	7 Days to Extraction
PCBs (Solid)	Glass (Soil Jar)	60 (Teflon cap)	NP, Cool 6°C	14 Days
*PCBs/Pesticides (Water)	Glass (Amber)	2 (each) 1000 (Teflon cap)	NP, Cool 6°C	7 Days to Extraction
pH	Plastic	125	NP, Cool 6°C	Immediately
PVOCs (Solids)	Glass (Teflon cap)	60	Methanol, Cool 6°C	21 Days
PVOCs (Water)	Glass (VOC vial)	2 (each) 40	HCl, Cool 6°C	14 Days
Pentachlorophenol	Amber Vials	3 amber vials from EHL w/Chlorinated Acids on Label		
Percent Acidity (Water)	Plastic	250	NP, Cool 6°C	14 Days
Percent Acidity (Soil)	Glass (Amber)	1000	NP, Cool 6°C	24 Hours
Percent Ash	Plastic	60	NP	NS
Percent Chlorine (Soil)	Glass (Amber)	1000	NP, Cool 6°C	14 Days
Phenols (4AAP)	Glass	2 (each) 250	Sulfuric, Cool 6°C	28 Days
Phosphorus (Solid)	Plastic	60	NP, Cool 6°C	28 Days
Phosphorus (Dis. react) (Ortho Phos)	Plastic	250	NP, Cool 6°C	48 Hrs.
Phosphorus (Soluble)	Plastic	250	NP, Cool 6°C	NS
Phosphorus (Total)	Plastic	250	Sulfuric, Cool 6°C	28 Days
Phosphorus (Total Diss)	Plastic	250	Sulfuric, Cool 6°C	28 Days
Phosphorus-Total React (Ortho phos)	Plastic	250	NP, Cool 6°C	2 Days
Radionuclides: Radon 222	Glass vials	2 (each) 40 vial Radon Kit from EHL	NP	4 Days
Radionuclides: Gross Alpha Gross Beta/Alpha Uranium Radium 226 Radium 228	Plastic (EHL)	1 Liter for each	HNO3	6 Months
Silica (Total)	Plastic	125	NP, Cool 6°C	28 Days
Silica (Reactive)				28 Days
Silica / Silicate	Plastic	125	NP, Cool 6°C	28 Days
Solids (Volatile)	Plastic	125	NP, Cool 6°C	7 Days
Solids (T. Dissolved)	Plastic	125	NP, Cool 6°C	7 Days
Solids (T. Fixed)	Plastic	125	NP, Cool 6°C	7 Days
Solids (T. Suspended)	Plastic	125	NP, Cool 6°C	7 Days
Solids on Solids	Plastic	60	NP, Cool 6°C	7 Days
Sulfate	Plastic	125	NP, Cool 6°C	28 Days
Sulfate (Dissolved)	Plastic	125	NP, Cool 6°C	28 Days
Sulfate (Soluble)	Plastic	125	NP, Cool 6°C	28 Days
Sulfide	Plastic	500	Zinc Acetate & NaOH 4 tabs	7 Days
Sulfide (Reactive)	Plastic	125	NP (Cool, Dark)	24 Hours/ASAP

TEST/PARAMETER	CONTAINER	CONTAINER SIZE (mLs)	PRESERVATION	HOLD TIME
Sulfite	Plastic	250	EDTA	Immediately
Sulfur (total)	Plastic	125	NP, Cool 6°C	No Hold Time
Surfactant (MBAS)	Plastic	960	NP, Cool 6°C	48 Hrs
Tannin & Lignin	Plastic	500	NP, Cool 6°C	ASAP
TCDD/TCDF	Glass (Amber)	2 x 1000	NP, Cool 6°C	7 Days
TOX	Glass (Amber)	2 (each) 300	Sulfuric, Cool 6°C	28 Days
TOC (Water)	Glass/Plastic	125	H ₂ SO ₄ , Cool 6°C	28 Days
TOC (Soil)	Glass or plastic (Soil jar)	125	NP, Cool 6°C	28 Days
Turbidity	Plastic	960	NP, Cool 6°C	48 Hrs
TCLP (VOCs) Solids	Plastic Glass (Teflon cap)	250 2 (each) 100 (DRO-type bottles)	NP, Cool 6°C NP, Cool 6°C	14 Days to Extraction
TCLP (Semi-Vol) Solids	Plastic	500	NP, Cool 6°C	14 Days to Extraction
TCLP (Metals) Solids	Plastic	500	NP, Cool 6°C	6 Months After Extraction
Total Trihalomethanes (Water)	Glass (VOC vial)	2 (each) 40	(0.05 grams) Ascorbic Acid HCL (0.5 mLs) in a 4 mL vial, Cool 6°C	14 Days
VOCs (Water)	Glass (VOC vial)	2 (each) 40	HCl, Cool 6°C	14 Days
VOCs (Soil) Methanol Preserved	Glass Amber (Soil Jar)	2 (each) 60 (Teflon cap)	Methanol, Cool 6°C	21 Days
*VOCs - Semi Volatiles (Water)	Glass (Amber)	2 (each) 1 Liter (Teflon cap)	NP, Cool 6°C	7 Days to Extraction
VOCs - Semi Volatiles (Soil)	Glass Amber (Soil Jar)	125 Short Wide-Mouth (Teflon cap)	NP, Cool 6°C	14 Days
VOC - EDB/DBCP	Glass	3 (each) 40	Sodium Thiosulfate, Cool 6°C	14 days
Method 525	Glass Amber	3 (each) 1 Liter Amber	Sodium Sulfite w/HCL, Cool 6°C	7 Days to Extraction

† = Information is subject to change based on method and administrative code revisions.

A = (0.6 grams/Liter, or 0.15 grams/250 mL of Ascorbic Acid should only be used in the presence or residual chlorine)

NS = Not Specified

LANGLIER INDEX – ALK, TDS, CALCIUM, HARDNESS – Field Temperature, Field pH – IMMEDIATELY

*Under specific conditions 1 bottle may be used.

Sample bottle sizes are subject to change due to individual project sampling requirements.

SAMPLE COLLECTION AND CHAIN OF CUSTODY RECORD

NORTHERN LAKE SERVICE, INC.

Wisconsin Lab Cert. No. 721026460
WI DATCP 105-000330

Analytical Laboratory and Environmental Services
400 North Lake Avenue • Crandon, WI 54520-1298
Tel: (715) 478-2777 • Fax: (715) 478-3060

CLIENT	
ADDRESS	
CITY	STATE ZIP
PROJECT DESCRIPTION / NO.	QUOTATION NO.
DNR FID #	DNR LICENSE #
CONTACT	PHONE
PURCHASE ORDER NO.	FAX

MATRIX:
SW = surface water
WW = waste water
GW = groundwater
DW = drinking water
TIS = tissue
AIR = air
SOIL = soil
SED = sediment
PROD = product
SL = sludge
OTHER

ANALYZE PER ORDER OF ANALYSIS

USE BOXES BELOW: Indicate Y or N if GW Sample is field filtered.
Indicate G or C if WW Sample is Grab or Composite.



NO. 135028

ITEM NO.	NLS LAB. NO.	SAMPLE ID	COLLECTION		MATRIX (See above)	PARAMETER												COLLECTION REMARKS (i.e. DNR Well ID #)	
			DATE	TIME															
1.																			
2.																			
3.																			
4.																			
5.																			
6.																			
7.																			
8.																			
9.																			
10.																			

Reorder from CURTIS1000 Midwest Operations 1-800-888-6882

COLLECTED BY (signature)	CUSTODY SEAL NO. (IF ANY)		DATE/TIME	REPORT TO
RELINQUISHED BY (signature)	RECEIVED BY (signature)	DATE/TIME		
DISPATCHED BY (signature)	METHOD OF TRANSPORT	DATE/TIME		
RECEIVED AT NLS BY (signature)	DATE/TIME	CONDITION	TEMP	
COOLER #	REMARKS & OTHER INFORMATION			
PRESERVATIVE: NP = no preservative S = sulfuric acid	OH = sodium hydroxide HA = hydrochloric & ascorbic acid H = hydrochloric acid	WDNR FACILITY NUMBER	E-MAIL ADDRESS	

IMPORTANT:
1. TO MEET REGULATORY REQUIREMENTS, THIS FORM **MUST** BE COMPLETED IN DETAIL AND INCLUDED IN THE COOLER CONTAINING THE SAMPLES DESCRIBED.
2. PLEASE USE ONE LINE PER SAMPLE. **NOT** PER BOTTLE.
3. RETURN THIS FORM WITH SAMPLES - CLIENT MAY KEEP PINK COPY.
4. PARTIES COLLECTING SAMPLE, LISTED AS **REPORT TO** AND LISTED AS **INVOICE TO** AGREE TO STANDARD TERMS & CONDITIONS ON REVERSE.

ORIGINAL COPY

Appendix E



Blank page





Sediment Characteristics and Diffusive Phosphorus Fluxes in Lac Courte Oreilles, Wisconsin



Near the outflow of Lac Courte Oreilles, Wisconsin

17 September, 2013

William F. James
University of Wisconsin - Stout
Sustainability Sciences Institute
Menomonie, Wisconsin 54751
715-338-4395
williamfjames@charter.net
jamesw@uwstout.edu

ABSTRACT

Intact sediment cores were collected in Musky, Stucky, West, Central, and East Bays of Lac Courte Oreilles in 2012 to measure diffusive phosphorus (P) flux in the laboratory under oxic (i.e., aerobic) and anoxic (i.e., anaerobic) conditions and quantify fractions of sediment P that are biologically-labile (i.e., subject to recycling and flux to the overlying water column) and biologically-refractory (i.e., relatively inert from recycling pathways and subject to burial) in the upper 10-cm sediment layer. In particular, the shallow Musky Bay and, to a lesser extent, Stucky Bay, have experienced an increase in riparian housing development and cranberry bog farming as well as increased growth of submersed aquatic macrophytes and associated metaphyton mats in recent decades, suggesting the possibility that accelerated sediment and associated nutrient inputs might be exacerbating internal P loading. In the more shallow Musky and Stucky Bays exposed to cranberry bog point-source inputs, both oxic and anoxic P fluxes were greatest at Musky Bay 1, located immediately downstream of a cranberry bog. The mean anoxic P flux of $2.96 \text{ mg/m}^2 \text{ d}$ (incubated at 25°C) was very high and reflected mesotrophic to eutrophic conditions. Concentrations of sediment total P, loosely-bound P, iron-bound P, and labile organic P, all biologically-labile and subject to recycling pathways, were also highest at Musky Bay 1, relative to Musky Bay 2, which was located a considerable distance from the cranberry bog input. Phosphorus flux from sediment also occurred under oxic conditions ($0.31 \text{ mg/m}^2 \text{ d}$) at Musky Bay 1 and represented a potentially significant internal P load. Anoxic diffusive P fluxes for sediments located in the deeper West, Central, and East Bays, were high (incubated at 12°C ; range = 3.01 to $5.10 \text{ mg/m}^2 \text{ d}$), coinciding with very high concentrations of redox-sensitive iron-bound P in the sediment. In particular, iron-bound P accounted for over 50% of the total sediment P at these stations and mean concentrations exceeded 1.8 to 3.0 mg/g in West and East Bays.

Overall, sediments exhibited a very high moisture content, low bulk density, and considerable organic matter content (range = 23% to 52%). Organic matter content was highest in the macrophyte-dominated shallow Musky and Stucky Bays. Total P (range = 1.2 to 4.8 mg/g) and total iron (Fe; range = 44 to 81 mg/g) concentrations were very high

in the deeper West, Central, and East Bays and the Fe:P ratio ranged between 17:1 and 38:1. These patterns probably reflected the outcome of sediment focusing processes as total P concentrations were enriched in redox-sensitive P, aluminum-bound P, calcium-bound P due to sediment transport and accumulation during periods of turnover. Total P concentrations were more moderate (range = 0.56 to 0.91 mg/g) in the shallower Musky and Stucky Bays and the labile organic P fraction accounted for the majority of the biologically-labile P (range = 52% to 75% of the biologically-labile P). Mean iron-bound P concentrations were also more moderate in the shallow bays, ranging between 0.05 and 0.17 mg/g and accounting for ~ 18% to 27% of the biologically-labile P.

OBJECTIVES

The objectives of these investigations were to 1) directly measure rates of phosphorus (P) release from sediment under a controlled laboratory environment as a function of aerobic and anaerobic conditions and 2) determine sediment characteristics and concentrations of biologically labile (i.e., active in recycling and sediment internal P loading) and refractory (i.e., relatively inert to recycling and subject to burial) P at various stations (Musky Bay, Stucky Bay, west, and central basins) in the Lac Courte Oreilles. This information is needed for future P budgetary analysis and TMDL (Total Maximum Daily Load) development of the system.

APPROACH

Laboratory determination of rates of phosphorus release under different environmental conditions

The goals of this task were to measure rates of P release from sediments as a function of oxidation-reduction condition (i.e., redox; aerobic or anaerobic conditions) in order to evaluate the importance of this source relative to other P inputs to the lake. Experimental procedures followed those in James (2011). Undisturbed replicate (3 per redox condition) sediment cores were collected in Musky Bay, Stucky Bay, and the West, Central, and

East Bays of Lac Courte Oreilles on 21 August, 2012, for determination of rates of P release from sediment (**Figure 1 and Table 1**). An unusual, as yet unidentified, biological growth was observed in some of the cores incubated under anoxic conditions (**Figure 2**) which affected P release rates. In order to reduce variation in rates associated with this pattern, an additional three replicate intact sediment cores each were collected in Musky, West, Central, and East Bays on 31 August, 2012, for determination of rates of P release under anoxic conditions.

A gravity sediment coring device (Aquatic Research Instruments, Hope ID) equipped with an acrylic core liner (6.5-cm ID and 50-cm length) was used to collect sediment. The core liners, containing both sediment and overlying water, were immediately sealed using rubber stoppers and stored in a covered container until analysis. Additional lake water was collected for incubation with the collected sediment.

In the laboratory, sediment cores were carefully drained of overlying water and the upper 10 cm layer was transferred intact to a smaller acrylic core liner (6.5-cm dia and 20-cm ht) using a core remover tool. Water collected from the lake was filtered through a glass fiber filter (Gelman A-E); 300 mL was then siphoned onto the sediment contained in the small acrylic core liner without causing sediment resuspension. Sediment incubation systems, therefore, consisted of the upper 10-cm of sediment and filtered overlying water contained in acrylic core liners that were sealed with rubber stoppers (**Figure 3**). The sediment incubation systems were placed in a darkened environmental chamber and incubated at a constant temperature for up to 2 weeks or longer. The incubation temperature was maintained at 25 °C for the shallower Musky and Stucky Bay stations and at 12 °C for the deeper West, Central, and East Bay stations to simulate average summer temperatures. The oxidation-reduction environment in each system was controlled by gently bubbling either air (aerobic) or nitrogen (anaerobic) through an air stone placed just above the sediment surface. Bubbling action ensured complete mixing of the water column but did not disrupt the sediment. Anoxic conditions were verified using a dissolved oxygen electrode.

Water samples for soluble reactive phosphorus (SRP) were collected at one to three day intervals over the entire incubation period. Samples (10 mL) were collected from the center of each sediment incubation system using a syringe and immediately filtered through a 0.45 μm membrane syringe filter. The water volume removed from each system during sampling was replaced by addition of filtered lake water preadjusted to the proper oxidation-reduction condition. These volumes were accurately measured for determination of dilution effects. SRP was measured colorimetrically using the ascorbic acid method (APHA 2005). Rates of SRP release from the sediment ($\text{mg}/\text{m}^2 \text{ d}$) were calculated as the linear change in concentration in the overlying water divided by time and the area of the incubation core liner. Regression analysis was used to estimate rates over the linear portion of the data.

Sediment textural and chemical properties

The upper 10 cm layer of an additional three replicate cores collected at each station was sectioned for analysis of moisture content (%), sediment density (g/mL), loss on ignition (i.e., organic matter content, %), loosely-bound P, iron-bound P, aluminum-bound P, calcium-bound P, labile and refractory organic P, total P, total iron (Fe), total aluminum (Al), and total calcium (Ca; all expressed at mg/g dry sediment mass). A known volume of sediment was dried at 105 $^{\circ}\text{C}$ for determination of moisture content and sediment density and burned at 500 $^{\circ}\text{C}$ for determination of loss-on-ignition organic matter content (Håkanson and Jansson 2002). Additional sediment was dried to a constant weight, ground, and digested for analysis of total P, Fe, Al, Ca, and S using standard methods (ICP-AA Spectrometry; APHA 2005).

Phosphorus fractionation was conducted according to Hieltjes and Lijklema (1980), Psenner and Puckso (1988), and Nürnberg (1988) for the determination of ammonium-chloride-extractable P (loosely-bound P), bicarbonate-dithionite-extractable P (i.e., iron-bound P), sodium hydroxide-extractable P (i.e., aluminum-bound P), and hydrochloric acid-extractable P (i.e., calcium-bound P; **Table 2**). A subsample of the sodium hydroxide extract was digested with potassium persulfate to determine nonreactive sodium

hydroxide-extractable P (Psenner and Puckso 1988). Labile organic P was calculated as the difference between reactive and nonreactive sodium hydroxide-extractable P. Refractory organic P was estimated as the difference between total P and the sum of the other fractions.

The loosely-bound and iron-bound P fractions are readily mobilized at the sediment-water interface as a result of bacterial metabolism under anaerobic conditions that lead to desorption of P from sediment and diffusion into the overlying water column (Mortimer 1971, Boström 1984, Nürnberg 1988; **Table 2**). The sum of the loosely-bound and iron-bound P fraction is redox-sensitive P (i.e., the P fraction that is active in P release under anaerobic and reducing conditions). In addition, labile organic P can be converted to soluble P via bacterial mineralization (Jensen and Andersen 1992) or hydrolysis of polyphosphates stored in bacterial cells to soluble P under anaerobic conditions (Gächter et al. 1988; Gächter and Meyer 1993; Hupfer et al. 1995). The sum of redox-sensitive P and labile organic P is biologically-labile P. This fraction is generally active in recycling pathways that result in exchanges of phosphate from the sediment to the overlying water column (i.e., internal P loading) and potential assimilation by algae. In contrast, aluminum-bound, calcium-bound, and refractory organic P fractions are more chemically inert and subject to burial rather than recycling.

RESULTS AND INTERPRETATION

Diffusive P flux

Soluble P mass and concentration increased in the overlying water column of all sediment systems maintained under anoxic conditions (**Figures 4, 5, and 6**). In Musky Bay, soluble P mass and concentration increases were greatest for sediment cores collected at station 1 versus station 2 (**Figure 4**), resulting in a relatively high mean anoxic P release rate of $2.96 \text{ mg/m}^2 \text{ d}$ ($\pm 0.48 \text{ SE}$; **Table 3**) for Musky Bay 1. A notable exception to this pattern was minor increase in P mass and concentration for one of the replicate sediment incubation systems collected at Musky Bay 1, which coincided with

biological growth of a fungus (i.e., triangle symbol in **Figure 4** and c.f.; **Figure 2**). In contrast, the mean anoxic P release rate for Musky Bay 2 was lower at $0.46 \text{ mg/m}^2 \text{ d}$ ($\pm 0.06 \text{ SE}$; **Table 3**). The mean soluble P concentration maximum at the end of the incubation period was also higher for Musky Bay 1 at 0.611 mg/L ($\pm 0.153 \text{ SE}$) compared to 0.057 mg/L ($\pm 0.011 \text{ SE}$) for Musky Bay 2. In Stucky Bay, soluble P mass and concentration increases were greatest at the deeper station 2 (**Figure 5**) and the mean anoxic P release rate was relatively high at $3.63 \text{ mg/m}^2 \text{ d}$ ($\pm 0.58 \text{ SE}$; **Table 3** and **Figure 6**). The mean anoxic P release rate for shallower Stucky Bay 1 was lower at $0.39 \text{ mg/m}^2 \text{ d}$ ($\pm 0.09 \text{ SE}$; **Table 3** and **Figure 6**). The mean soluble P concentration maximum at the end of the incubation period was 0.094 mg/L ($\pm 0.224 \text{ SE}$) and 0.626 mg/L ($\pm 0.224 \text{ SE}$) for Stucky Bay 1 and 2, respectively

Even though the West, Central, and East Bays sediment systems were incubated at a much lower temperature (i.e., 12°C) to simulate summer hypolimnetic conditions at these much deeper stations, increases in soluble P mass and concentration were substantial under anoxic conditions (**Figure 7**). With the exception of one sediment incubation system (East Bay), both soluble P mass and concentration increased linearly between ~ day 5 and day 18. Similar to Musky Bay 1, the East Bay outlier coincided with the unusual fungal growth (**Figure 2**). The mean maximum soluble P concentration at the end of the incubation period was relatively high at 0.688 mg/L ($\pm 0.139 \text{ SE}$), 0.678 mg/L ($\pm 0.129 \text{ SE}$), and 0.669 mg/L ($\pm 0.100 \text{ SE}$) for West, Central, and East Bay sediment systems, respectively. Mean anoxic P release rates were high at these deeper stations and indicative of eutrophic conditions (Nürnberg 1988), ranging between ~ 3 and $5 \text{ mg/m}^2 \text{ d}$ (**Table 3** and **Figure 8**).

Soluble P mass and concentration increases were much lower to minimal under aerobic conditions, particularly for sediment cores collected in Stucky Bay (**Figure 9 and 10**). Although the mean oxic P release rate was near detection limits for sediment cores collected at Musky Bay 2, and Stucky Bay 1 and 2, it was relatively high at $0.31 \text{ mg/m}^2 \text{ d}$ ($\pm 0.07 \text{ SE}$) for sediment cores collected from Musky Bay 1 (**Table 3** and **Figure 6**) and

represented a potentially important source of P to the water column, even under aerobic conditions.

Sediment Characteristics

Overall, surface sediments in Musky Bay exhibited very high mean moisture content (greater than 95%) and low mean bulk density (near 1 g/m³), indicative of very flocculent sediment (**Table 4** and **Figure 11**). Sediment cores collected in Musky Bay exhibited the greatest mean moisture content relative to other stations. Although sediment moisture content was slightly lower in Stucky Bay 2, and West, Central and East Bays, the means exceeded 90%. Mean sediment organic matter content in Musky Bay exceeded 40% (range = 43% to 52%), coinciding with abundant macrophyte vegetation. Mean sediment organic matter content was also relatively high for macrophyte-dominated Stucky Bay at ~30% to 38%. West, Central, and East Bay mean sediment organic matter content was also relatively high and ranged between 23% and 28%.

Mean sediment total P concentrations were moderate and less than 1 mg/g at the shallow Musky and Stucky Bay stations (**Table 5** and **Figure 12**). However, the greatest mean sediment total P occurred at Musky Bay 1, nearest to the cranberry farm discharge, at 0.91 mg/g (± 0.09 SE; **Figure 12**). In contrast, sediment total P was much higher at the deeper Bay stations. In particular, the mean concentration was near 3 mg/g at the West Bay station and it exceeded 4.5 mg/g at the East Bay station (**Table 5** and **Figure 12**). These ranges were exceptionally high compared to concentrations measured in some other lake sediments (n=13 lakes) in the western Wisconsin region (**Figure 13**).

The biologically-labile P fraction in the upper 10-cm sediment layer represented between 47% to greater than 75% of the sediment total P at all stations, suggesting the potential for P recycling and internal P loading (**Table 5**). Biologically-labile P concentrations were high and represented greater than ~ 65% of the sediment total P for stations located in the deeper West, Central, and East Bays. This fraction accounted for 54% to 69% of the sediment total P in Musky Bay. Although slightly lower in Stucky Bay compared to

other stations, percentages ranged between 47% and 54%, indicating that at least half of the sediment total P was in potentially recyclable fractions.

For the shallow Musky and Stucky Bay sediment, the labile organic P fraction accounted for the majority of the biologically-labile P with ranges between 52% and 75% (**Figure 14**). Concentrations were greatest at Musky Bay 1 (0.32 mg/g; ± 0.05 SE), ~ 0.23 mg/g (± 0.06 SE), at Musky Bay 2, and less than 0.2 mg/g in Stucky Bay sediments (**Table 6** and **Figure 15**). Although lower in concentration compared to labile organic P, and generally accounting for a lower proportion of the biologically-labile P fraction, the mean loosely-bound P fraction was greatest at Musky Bay 1 versus the other shallow bay stations (**Figure 15**). Mean iron-bound P concentrations were moderate in the shallow bays, ranging between 0.05 and 0.17 mg/g (**Table 6** and **Figure 15**) and accounting for $\sim 18\%$ to 27% of the biologically-labile P (**Figure 14**). As with the other biologically-labile P fractions, the mean iron-bound P concentration was greatest at Musky Bay 1 (**Figure 15**).

In contrast to the shallow bay sediments, the biologically-labile P fraction was overwhelmingly dominated by iron-bound P (range = 72% to 85%) for sediments located in the deeper West, Central, and East Bays of Lac Courte Oreilles (**Figure 16**). Concentrations of iron-bound P were also very high at these stations, ranging between 1.9 and 3.1 mg/g (**Table 6** and **Figure 15**) and falling well above the upper 25% quartile compared to some other lakes located in western Wisconsin (**Figure 13**).

Refractory organic P accounted for a majority of the biologically-refractory P fraction for both stations located in Musky Bay and the Stucky Bay 1 station (**Figure 14** and **15**). Refractory organic P concentrations also tended to be higher at these stations compared to the deeper West, Central, and East Bay stations (**Figure 15** and **16**), which coincided with the prevalence of submersed macrophytes in the shallow regions of these bays. This pattern indicated that a portion of the sediment total P was likely tied up in refractory organic forms, perhaps derived from aquatic macrophyte decomposition, and subject to burial. Overall, however, concentrations of refractory organic P were low relative to some other lakes in the western Wisconsin region (**Figure 13**). After refractory organic P,

the aluminum-bound and calcium-bound P fractions tended to co-dominate the remaining biologically-refractory P (**Figure 14**) and concentrations were similar at the Musky Bay 1 and 2 and Stucky Bay 1 stations (**Figure 15**). In contrast, calcium-bound P accounted for the majority (55%) of the biologically-refractory P fraction at Stucky Bay 2 (**Figure 14**).

At the deeper West, Central, and East Bay sediment stations, aluminum-bound P represented 74%, 37%, and 84% of the biologically-refractory P, respectively (**Figure 16**). In addition, concentrations of this refractory constituent were much higher in the deeper bays versus shallow Musky and Stucky Bays (**Figure 15**) and fell above the upper 25% quartile compared to other lakes in western Wisconsin (**Figure 13**). Calcium-bound P concentrations were also generally greater, while refractory organic P was lower, at the deeper West, Central and East Bay stations relative to the shallow Musky and Stucky Bay stations (**Figure 15**).

Total Fe concentrations were very high for sediments located in West, Central, and East Bays and Stucky Bay 1 (**Figure 17**). By comparison, total Fe concentrations were much lower at Musky Bay 1 and 2 and Stucky Bay 1. Total Ca exhibited the opposite pattern; they were higher at the shallow Musky and Stucky Bay 1 stations and slightly lower at the deeper stations (**Figure 17**). Mean total Al was lowest in Musky Bay and East Bay and slightly elevated in Stucky Bay 2, West, and East Bay sediments (**Figure 17**). Mean total S concentrations were similar and greatest at stations located in Musky Bay, Stucky Bay 1, and East Bay.

The Fe:P ratio was very high for nearly all sediments examined (**Figure 18**). In particular, in even though sediment total P concentrations were unusually high at the West, Central, and East Bay stations, the mean Fe:P ratio ranged between ~ 17:1 and 38:1, due to high Fe concentrations relative to P. Stucky Bay 2 sediments exhibited the greatest Fe:P ratio at 74:1. In contrast, it was relatively low at ~ 7:1 at Musky Bay 1. Ratios greater than 15 have been associated with regulation of P release from sediments under oxic (aerobic) conditions (Jensen et al. 1992). Higher binding efficiency for P at higher relative concentrations of Fe are suggested explanations for patterns reported by

Jensen et al. Oxic P release rates were lowest at Musky Bay 2, and Stucky Bay 1 and 2 and sediments at these locations exhibited an Fe:P ratio ranging between 15:1 and 74:1 (*Figure 19*), a pattern that could be attributed to the Jensen et al. model. In contrast, the lower mean Fe:P ratio at Musky Bay 1 coincided with some P release under oxic conditions (*Figure 19*). This pattern might be related to lower Fe binding efficiency for P at low Fe:P ratios (i.e., < 15).

SUMMARY AND CONCLUSIONS

Diffusive P fluxes for sediments located in the deeper West, Central, and East Bays, were relatively high under anoxic conditions, coinciding with very high concentrations of redox-sensitive iron-bound P in the sediment. In particular, iron-bound P accounted for over 50% of the total sediment P at these stations, mean concentrations exceeded 1.8 to 3.0 mg/g in West and East Bays, and they fell well above the upper 25% quartile compared to some other lakes in western Wisconsin. Other research has demonstrated significant positive relationships between anoxic P flux and the concentration of iron-bound P, with anoxic P fluxes increasing as a linear function of iron-bound P concentration (Boström 1984, Nürnberg 1988). Sediment total Fe concentrations were also very high, falling well above the upper range of concentrations reported in Barko and Smart (1986), and the sediment Fe:P ratio exceeded 16 at these bay stations. These patterns strongly suggested that anoxic P flux was probably coupled with bacterially-mediated reduction of Fe at the sediment-water interface. Under aerobic conditions, Fe is in an oxidized state (Fe^{+3}) as an Fe-oxyhydroxide ($\text{Fe}(\text{OOH})$; solid precipitate) and strongly adsorbs phosphate, resulting in low diffusive P flux from sediments (Mortimer 1971) especially when the Fe:P ratio is high (i.e., greater than ~ 15; Jensen et al. 1992). $\text{Fe}(\text{OOH})$ becomes reduced to soluble Fe^{+2} in conjunction with bacterial metabolism under anaerobic conditions, resulting in desorption of phosphate and much higher rates of diffusive P flux, as observed for West, Central, and East sediments incubated under anoxic conditions.

Information on the seasonal accumulation of hypolimnetic soluble Fe and P during periods of summer anoxia, as well as an estimate of the soluble Fe:P ratio in the hypolimnion, will be needed in conjunction with sediment P dynamics reported in this study in order to provide greater insight into internal P loading dynamics in the West, Central, and East Bays. For instance, a low soluble Fe:P ratio in the hypolimnion (versus that in the sediment) would suggest that sediment Fe^{2+} is being removed from recycling in the water column via bacterially-mediated sulfate reduction and formation of iron sulfide ($\text{FeS}_{(\text{solid})}$), which is generally inert to further recycling and subject to burial. Another potential Fe sequestration and removal mechanism is chelation with organic carbon. More importantly, binding of PO_4^{3-} by $\text{Fe}(\text{OOH})$ during periods of reoxygenation is inefficient at hypolimnetic soluble Fe:P ratios less than $\sim 3.6:1$ w:w (molar ratio of $\sim 2:1$; Gunnars and Blomqvist 1997), resulting in potential soluble P entrainment into the surface waters for algal assimilation and growth to nuisance bloom concentrations, particularly during periods of summer metalimnetic migration and fall turnover.

Typically, rates of P release from sediments are sensitive to ambient water temperature conditions and can increase exponentially with increasing temperature (James et al. 2004). Even though ambient water temperature in the hypolimnion was only $\sim 12^\circ\text{C}$ during the late summer, laboratory-determined anoxic diffusive P fluxes for the West, Central, and East Bay stations were very high and comparable to those measured at the same temperature for eutrophic Lake Pepin (Upper Mississippi River; west-central Wisconsin). Thus, future anoxic diffusive P fluxes from sediment in these bays could potentially increase over current rates if hypolimnetic water temperatures increase as a result of climate change.

In the shallow Musky Bay, variations in both oxic and anoxic sediment diffusive P fluxes coincided with station proximity to the cranberry bog discharge on the eastern shoreline of the bay and variations in the concentration of Fe and P in the sediment. At Musky Bay 1, located immediately in front of the cranberry bog point-source discharge, the mean anoxic P release rate of $\sim 3 \text{ mg/m}^2 \text{ d}$ was very high and reflected mesotrophic to eutrophic conditions (Nürnberg 1988). Concentrations of sediment total P, loosely-bound

P, iron-bound P, and labile organic P, all biologically-labile and subject to recycling pathways, were also higher at Musky Bay 1 than at Musky Bay 2, which was located a considerable distance from the cranberry bog. Since anoxic diffusive P fluxes were also much lower at Musky Bay 2, differences between the two stations strongly suggested a probable connection between point-source P loading from the bog and localized influences on sediment P concentrations and anoxic P fluxes.

Patterns at Musky Bay 1 contrasted with much lower anoxic P fluxes at Stucky Bay 1, which was also located near another cranberry bog discharge. Stucky Bay 1 was positioned further away from that point-source discharge and located at a deeper water column depth than Musky Bay 1, so cranberry bog discharge influences, if any, may not have been clearly detected at that station. Analysis of sediment cores collected closer to the cranberry bog discharge point in Stucky Bay would be needed to improve the spatial resolution of sediment P distribution and dynamics in the bay. In addition, sediment focusing (Likens and Davis 1975) may have played a role in modifying the distribution of sediment in that region of the bay. Since the morphometry of Stucky Bay is relatively steep with a much smaller littoral region, wind-generated circulation and water column mixing during fall and spring turnover periods would promote scouring and erosion of sediments from shallow to deeper regions, ultimately resulting in the transport of sediment to deeper zones of accumulation in the bay. Finally, differences in point-source P loading (unknown) to each bay may also partially explain variations in anoxic P flux patterns between the two bays and need to be considered.

Anoxic P flux was also relatively high at Stucky Bay 2 and comparable to rates measured at Musky Bay 1. Furthermore, rates for both Stucky and Musky Bay appeared to be positively related to the concentration of iron-bound P in the sediment (**Figure 20**), which conformed to regression relationships found by Nürnberg (1988) for North American Lakes, indicating probable regulation of anoxic P flux by bacterially-mediated iron reduction.

Variations in oxic diffusive P flux in Musky and Stucky Bays were likely attributed to differences in the Fe:P ratio of the sediment. Jensen et al. (1992) found that oxic P fluxes increased as a function of decreasing Fe:P ratio below a threshold of ~ 15:1. He attributed this pattern to decreasing binding efficiency of Fe(OOH) for P as the ratio decreased below ~ 15:1 and suggested that a ratio of at least 15:1 or greater was optimal for complete P binding and control of diffusive P flux from sediment under oxic conditions. Indeed, the mean oxic diffusive P flux was highest at Musky Bay 1, which coincided with an Fe:P ratio that was just below the threshold found by Jensen et al. (1992). Although low compared to the mean anoxic P flux, results from Musky Bay 1 suggested that oxic P flux could be significant in this region and needs to be considered in the overall P budget of the Bay. Not considered in this study was the possible indirect role that macrophyte-mediated increases in pH may have on oxic P flux from sediments, particularly near Musky Bay 1. Elevated pH (i.e., 9.5 - 10.5) during macrophyte photosynthesis can induce ligand exchange, or replacement of PO_4 with OH^- on Fe(OOH), resulting in enhanced P release from sediment under oxic conditions (Boström et al. 1982; Drake and Heaney 1987). Elevated water temperature during unusually hot summer periods may also enhance biological processes, resulting in mineralization of organic P and enhanced P flux under oxic conditions (Søndergaard 1989).

In general, variations in sediment physical and chemical constituent characteristics coincided with bay water column depth and aquatic habitat (i.e., littoral versus profundal zones). At littoral stations, it also appeared that many sediment characteristics were significantly different at Musky Bay 1 versus the other shallow littoral stations (i.e., Musky Bay 2 and Stucky Bay 1), which may be due to its close proximity to the cranberry point-source discharge. Musky Bay 1 sediment generally exhibited significantly greater concentrations of loosely-bound, iron-bound, and labile organic P compared to Musky Bay 2 and Stucky Bay 1 sediments. Higher biologically-labile P concentrations also coincided with greater diffusive P fluxes under both oxic and anoxic conditions, suggesting a possible linkage to point-source P inputs that needs to be explored in future research.

By comparison, West, Central and East Bay and to some extent, deeper, Stucky Bay 2 profundal sediments reflected the outcome of sediment focusing processes as total P concentrations were enriched in redox-sensitive P, aluminum-bound P, calcium-bound P due to sediment transport and accumulation during periods of turnover. Very high concentrations of total Fe in these bays probably reflect the local geology of the watershed. An unknown is the composition and mineral forms of Fe at these locations. In particular, Fitzpatrick et al. (2003) found that total Fe concentrations were depleted at the sediment surface, relative to deeper sediment layers, in a core collected in Musky Bay. They suggested that sulfate reduction to S and reaction with Fe to form $\text{FeS}_{(\text{solid})}$ may be occurring and noted a hydrogen sulfide odor, which is a characteristic product of sulfate reduction. This process essentially removes Fe from further oxidation-reduction reactions and adsorption-desorption interactions with P as discussed above. More information is needed on vertical variations in P and Fe concentrations in sediment cores collected at these deeper stations in order to better understand the role of sulfate reduction on Fe dynamics.

ACKNOWLEDGMENTS

I gratefully acknowledge Jeff Jackson, University of Wisconsin – Stout, for his participation in field sampling and laboratory experimental setup. I also thank C. Bruce Wilson for insightful discussions on Lac Courte Oreille and the Lac Courte Oreille Lake Association and Wisconsin DNR for funding this project.

REFERENCES

- APHA (American Public Health Association). 2005. Standard Methods for the Examination of Water and Wastewater. 21th ed. American Public Health Association, American Water Works Association, Water Environment Federation.
- Barko JW, Smart RM. 1986. Sediment-related mechanisms of growth limitation in submersed macrophytes. *Ecology* 67:1328-1340.
- Boström B. 1984. Potential mobility of phosphorus in different types of lake sediments. *Int. Revue. Ges. Hydrobiol.* 69:457-474.

Boström B, Jansson M, Forsberg C. 1982. Phosphorus release from lake sediments. *Arch Hydrobiol Beih Ergeb Limnol* 18:5-59.

Drake JC, Heaney SI. 1987. Occurrence of phosphorus and its potential remobilization in the littoral sediments of a productive English Lake. *Freshwat Biol* 17:513-523

Fitzpatrick F, Garrison PJ, Fitzgerald SA, Elder JF. 2003. Nutrient, trace-element, and ecological history of Musky Bay, Lac Courte Oreilles, Wisconsin, as inferred from sediment cores. US Geological Survey Water Resources Investigations Report 02-4225. Middleton, WI. 141 pp

Gächter R., Meyer JS, Mares A. 1988. Contribution of bacteria to release and fixation of phosphorus in lake sediments. *Limnol. Oceanogr.* 33:1542-1558.

Gächter R, Meyer JS. 1993. The role of microorganisms in mobilization and fixation of phosphorus in sediments. *Hydrobiologia* 253:103-121.

Gunnars A, Blomqvist S. 1997. Phosphate exchange across the sediment-water interface when shifting from anoxic to oxic conditions: An experimental comparison of freshwater and brackish-marine systems. *Biogeochemistry* 37:203-226.

Håkanson L, Jansson M. 2002. Principles of lake sedimentology. The Blackburn Press, Caldwell, NJ USA.

Hjieltjes AH, Lijklema L. 1980. Fractionation of inorganic phosphorus in calcareous sediments. *J. Environ. Qual.* 8: 130-132.

Hupfer M, Gächter R., Giovanoli R. 1995. Transformation of phosphorus species in settling seston and during early sediment diagenesis. *Aquat. Sci.* 57:305-324.

James WF. 2011. Variations in the aluminum:phosphorus binding ratio and alum dosage considerations for Half Moon Lake, Wisconsin. *Lake Reserv Manage* 27:128-137.

James WF, Barko JW. 2004. Diffusive fluxes and equilibrium processes in relation to phosphorus dynamics in the Upper Mississippi River. *River Res Applic* 20:473-484.

Jensen HS, Kristensen P, Jeppesen E, Skytthe A. 1992. Iron:phosphorus ratio in surface sediment as an indicator of phosphate release from aerobic sediments in shallow lakes. *Hydrobiol.* 235/236:731-743.

Likens GE, Davis MB. 1975. Post-glacial history of Mirror Lake and its watershed in New Hampshire, USA: An initial report. *Verh Intern Verein Limnol* 19:982-993.

Mortimer CH. 1971. Chemical exchanges between sediments and water in the Great Lakes – Speculations on probable regulatory mechanisms. *Limnol. Oceanogr.* 16:387-404.

Nürnberg GK. 1988. Prediction of phosphorus release rates from total and reductant-soluble phosphorus in anoxic lake sediments. *Can. J. Fish. Aquat. Sci.* 45:453-462.

Psenner R, Puckso R. 1988. Phosphorus fractionation: Advantages and limits of the method for the study of sediment P origins and interactions. *Arch. Hydrobiol. Biel. Erg. Limnol.* 30:43-59.

Søndergaard M. 1989. Phosphorus release from a hypereutrophic lake sediment: Experiments with intact sediment cores in a continuous flow system. *Arch Hydrobiol* 116:45-59.

Table 1. Redox (i.e., aerobic and/or anaerobic) conditions used for determination of rates of phosphorus release from sediment for various stations. The number of replicates are indicated for each redox conditions.							
Station	Depth (m)	Lat	Long	Redox and Temperature Condition			
				Aerobic Conditions		Anaerobic Conditions	
				Reps	Temp (C)	Reps	Temp (C)
Musky Bay 1	0.75	45.87639	-91.45389	3	25	6	25
Musky Bay 2	1.5	45.87611	-91.46806	3	25	3	25
Stucky Bay 1	1.5	45.90611	-91.47889	3	25	3	25
Stucky Bay 2	7.5	45.90327	-91.48114	3	25	3	25
West Bay	19.2	45.88961	-91.46352			6	12
Central Bay	17.7	45.89040	-91.44060			6	12
East Bay	27.1	45.89770	-91.39703			5	12

Table 2. Operationally-defined sediment phosphorus fractions based on sequential extraction.		
Variable	Extractant	Recycling potential
Loosely-bound P	1 M ammonium chloride	Biologically-labile; recycled via eH and pH reactions and equilibrium processes
Iron-bound P	0.11 M sodium bicarbonate-dithionate	Biologically-labile; recycled via eH and pH reactions and equilibrium processes
Labile organic P	persulfate digestion of the sodium hydroxide extract	Biologically-labile; recycled via bacterial mineralization of organic P and mobilization of polyphosphates stored in bacterial cells
Aluminum-bound P	0.1 N sodium hydroxide	Biologically-refractory and subject to burial
Calcium-bound P	0.5 N hydrochloric acid	Biologically-refractory and subject to burial
Refractory organic P	calculated as the difference between sediment total P and the sum of the other fractions	Biologically-refractory and subject to burial

Table 3. Mean rates of phosphorus (P) release for sediments collected in Lac Courte Orielles.						
Station	Diffusive P flux					
	Oxic			Anoxic		
	(mg m ⁻² d ⁻¹)	STDERR	n	(mg m ⁻² d ⁻¹)	STDERR	n
Musky Bay 1	0.31	0.07	3	2.96	0.48	6
Musky Bay 2	0.06	0.03	3	0.46	0.06	3
Stucky Bay 1	0.04	0.01	3	0.39	0.09	3
Stucky Bay 2	0.03	0.02	3	3.63	0.58	3
West Bay				3.01	0.54	6
Central Bay				5.10	0.68	6
East Bay				4.68	0.72	5

Table 4. Textural characteristics for sediments collected in Lac Courte Orielles.						
Station	Moisture Content	STDERR	Bulk Density	STDERR	Loss-on-ignition	STDERR
	(%)		(g/cm ³)		(%)	
Musky Bay 1	96.6	0.2	1.012	0.001	42.6	0.6
Musky Bay 2	96.2	0.3	1.012	0.001	52.1	1.5
Stucky Bay 1	94.1	0.3	1.023	0.001	37.9	0.1
Stucky Bay 2	92.5	0.1	1.033	0.001	30.2	0.4
West Bay	93.3	0.3	1.031	0.002	27.6	0.9
Central Bay	91.4	0.5	1.040	0.003	26.9	0.8
East Bay	94.0	0.4	1.029	0.002	23.2	1.2

Table 5. Concentrations of sediment total phosphorus (P), redox-sensitive P (Redox P; the sum of the loosely-bound and iron-bound P fraction), biologically-labile P (Bio-labile P; the sum of redox-P and labile organic P), and refractory P (the sum of the aluminum-bound, calcium-bound, and refractory organic P fractions) for sediments collected in Lac Courte Orielles. DW = dry mass.

Station	Total P		Redox P		Bio-labile P		Refractory P	
	(mg/g DW)	STDERR	(mg/g DW)	(% total P)	(mg/g DW)	(% total P)	(mg/g DW)	(% total P)
Musky Bay 1	0.908	0.090	0.300	33.1%	0.625	68.8%	0.296	32.6%
Musky Bay 2	0.572	0.072	0.077	13.5%	0.310	54.3%	0.262	45.7%
Stucky Bay 1	0.559	0.007	0.082	14.7%	0.263	47.0%	0.296	53.0%
Stucky Bay 2	0.563	0.055	0.142	25.2%	0.303	53.8%	0.306	54.3%
West Bay	2.997	0.223	1.978	66.0%	2.292	76.5%	0.848	28.3%
Central Bay	1.201	0.220	0.574	47.8%	0.769	64.0%	0.474	39.5%
East Bay	4.817	0.224	3.198	66.4%	3.627	75.3%	1.462	30.4%

Table 6. Mean concentrations of biologically-labile P for sediments collected in Lac Courte Orielles. DW = dry mass.						
Station	Redox-sensitive and biologically labile P					
	Loosely-bound P		Iron-bound P		Labile organic P	
	(mg/g DW)	STDERR	(mg/g DW)	STDERR	(mg/g DW)	STDERR
Musky Bay 1	0.131	0.045	0.170	0.041	0.324	0.046
Musky Bay 2	0.023	0.004	0.054	0.006	0.233	0.057
Stucky Bay 1	0.021	0.002	0.061	0.009	0.181	0.011
Stucky Bay 2	0.014	0.001	0.128	0.003	0.161	0.010
West Bay	0.083	0.007	1.895	0.076	0.314	0.018
Central Bay	0.022	0.004	0.552	0.145	0.194	0.030
East Bay	0.125	0.013	3.073	0.193	0.428	0.050

Table 7. Mean concentrations of biologically refractory P for sediments collected in Lac Courte Orielles. DW = dry mass.						
Station	Refractory P					
	Aluminum-bound P		Calcium-bound P		Refractory organic P	
	(mg/g DW)	STDERR	(mg/g DW)	STDERR	(mg/g DW)	STDERR
Musky Bay 1	0.110	0.013	0.068	0.007	0.117	0.061
Musky Bay 2	0.062	0.007	0.048	0.001	0.151	0.016
Stucky Bay 1	0.073	0.007	0.093	0.017	0.130	0.045
Stucky Bay 2	0.083	0.007	0.170	0.008	0.052	0.042
West Bay	0.623	0.087	0.194	0.006	0.030	0.015
Central Bay	0.174	0.023	0.211	0.008	0.089	0.042
East Bay	1.229	0.167	0.185	0.012	0.048	0.038

Table 8. Concentrations of sediment total iron (Fe), calcium (Ca), total aluminum (Al), total sulfur (S) and the Fe:P for sediments collected in Lac Courte Orielles. DW = dry mass.

Station	Total Fe (mg/g DW)	STDERR	Total Ca (mg/g DW)	STDERR	Total Al (mg/g DW)	STDERR	Total S (mg/g DW)	STDERR	Fe:P	STDERR
Musky Bay 1	6.19	0.43	6.11	0.36	3.89	0.42	6.27	0.26	7.0	1.0
Musky Bay 2	8.65	0.68	6.59	0.24	3.20	0.08	5.55	0.63	15.3	0.7
Stucky Bay 1	13.53	0.98	5.78	0.18	4.73	0.06	5.60	0.37	24.2	1.7
Stucky Bay 2	41.27	2.03	4.44	0.32	6.08	0.49	3.48	0.29	74.1	4.2
West Bay	50.17	1.84	4.43	0.05	5.72	0.23	5.03	0.14	16.9	0.8
Central Bay	44.07	2.03	4.57	0.04	7.47	0.35	4.78	0.25	38.4	4.7
East Bay	81.30	4.00	3.43	0.11	4.13	0.18	6.79	0.15	16.9	0.5

<to be added>

Figure 1. Sediment sampling station locations.

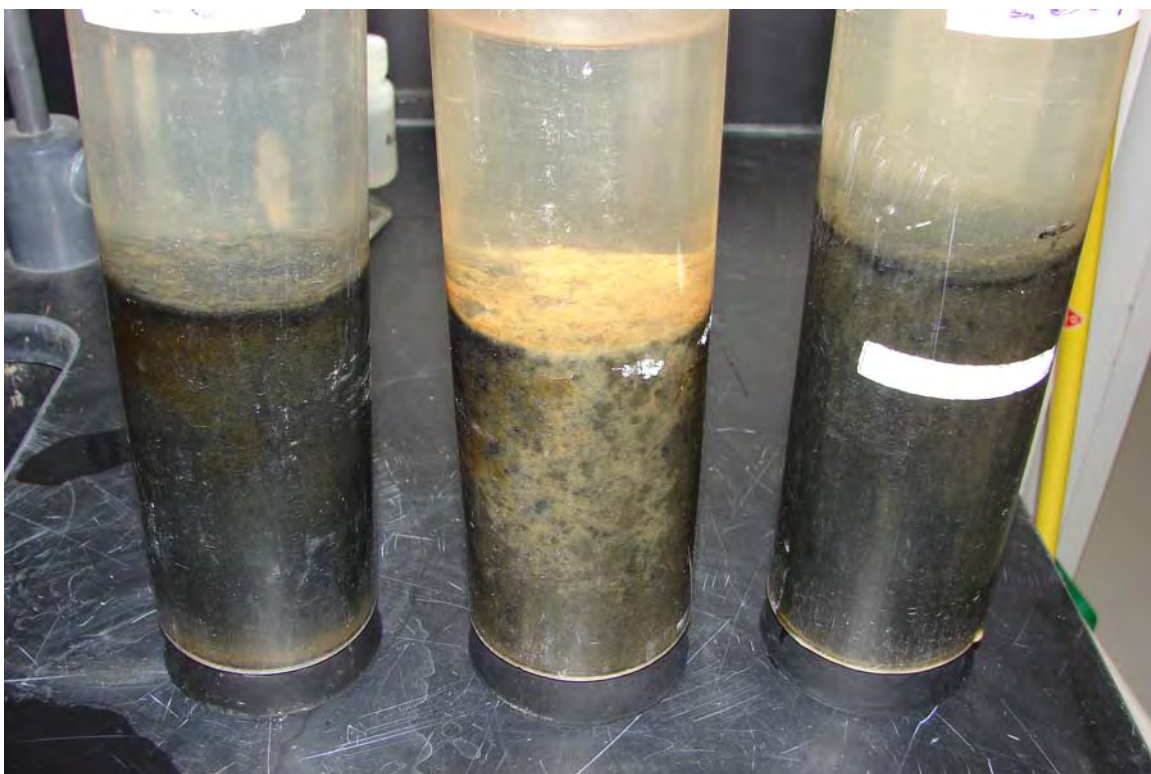


Figure 2. Intact sediments cores collected from East Bay and incubated under anoxic conditions. Please note biological growth in the middle core.



Figure 3. Sediment incubation system for measurement of diffusive phosphorus flux.

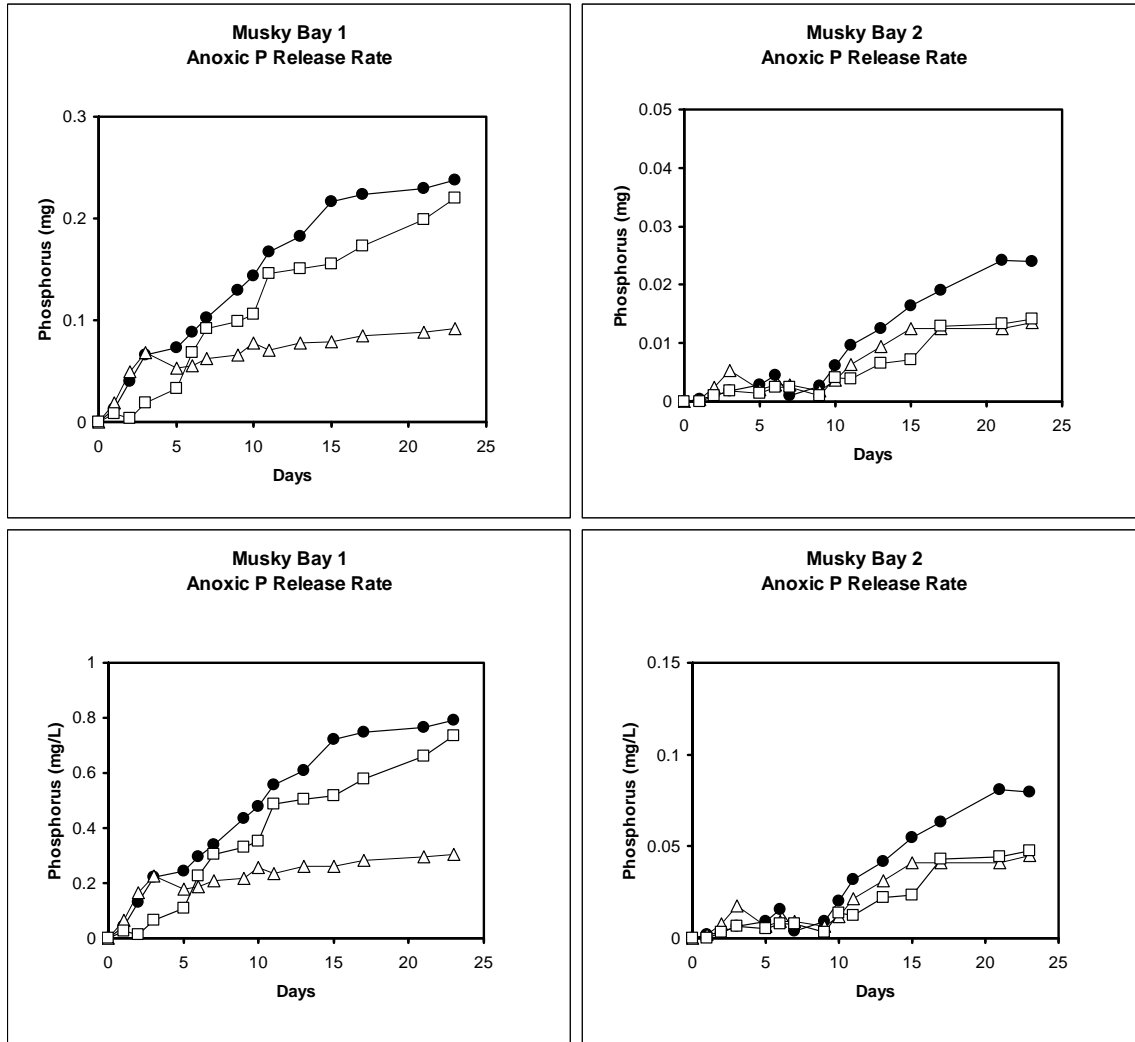


Figure 4. Changes in phosphorus (P) mass (upper panels) and concentration (lower panels) as a function of time for replicate sediment core incubation systems subjected to anoxic conditions. Please note scale differences between stations. Incubation temperature was 25 °C.

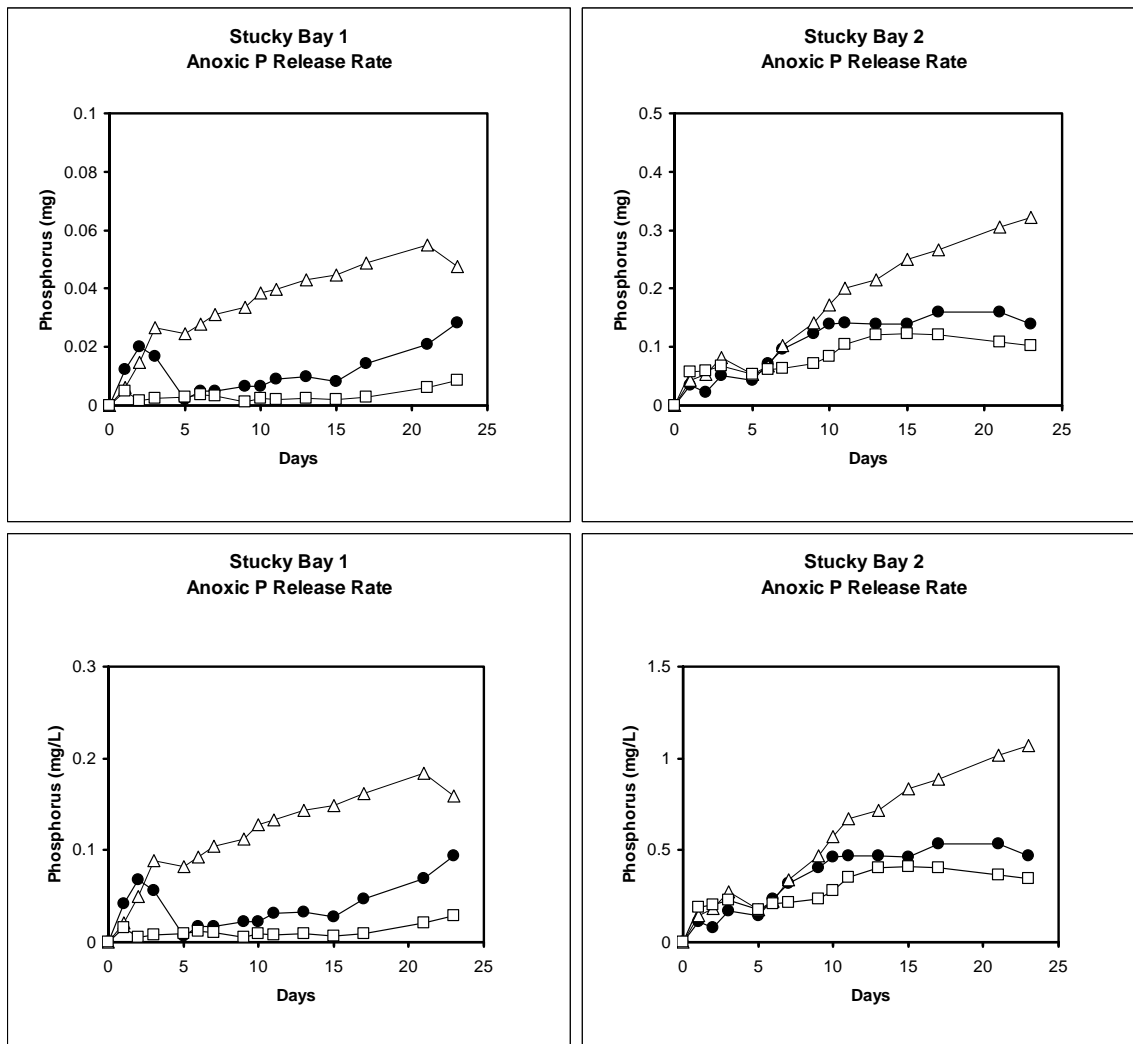


Figure 5. Changes in phosphorus (P) mass (upper panels) and concentration (lower panels) as a function of time for replicate sediment core incubation systems subjected to anoxic conditions. Please note scale differences between stations. Incubation temperature was 25 °C.

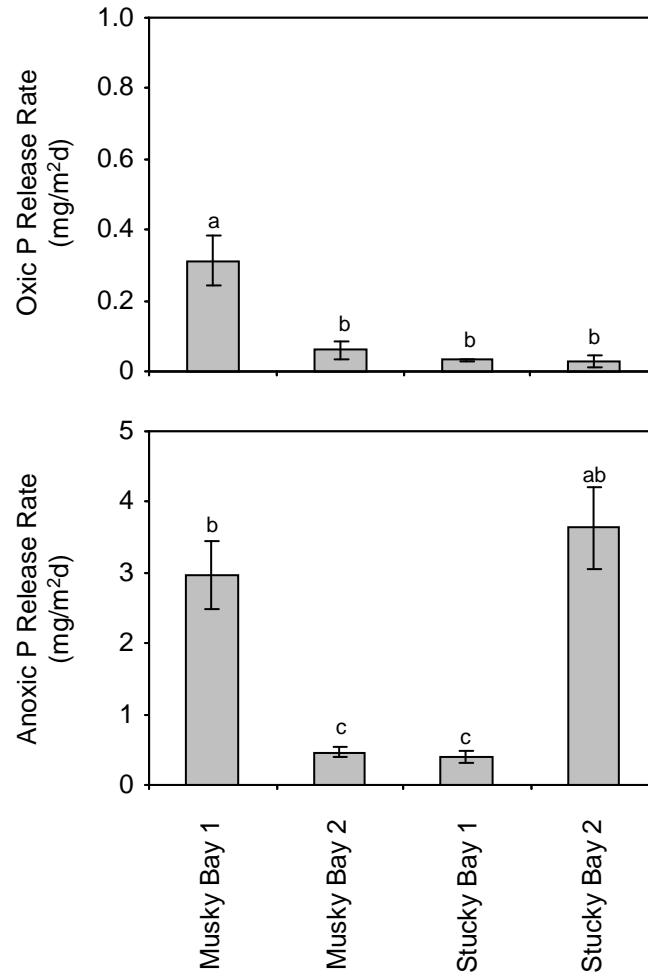


Figure 6. Mean (± 1 standard error) rates of diffusive phosphorus flux under oxic (upper panel) and anoxic conditions (lower panel) for sediment core incubation systems collected in shallow Musky and Stucky Bays of Lac Courte Oreilles. Incubation temperature was 25 oC. Different letters denote statistically significant differences based on ANOVA (Duncan-Waller; SAS 1994).

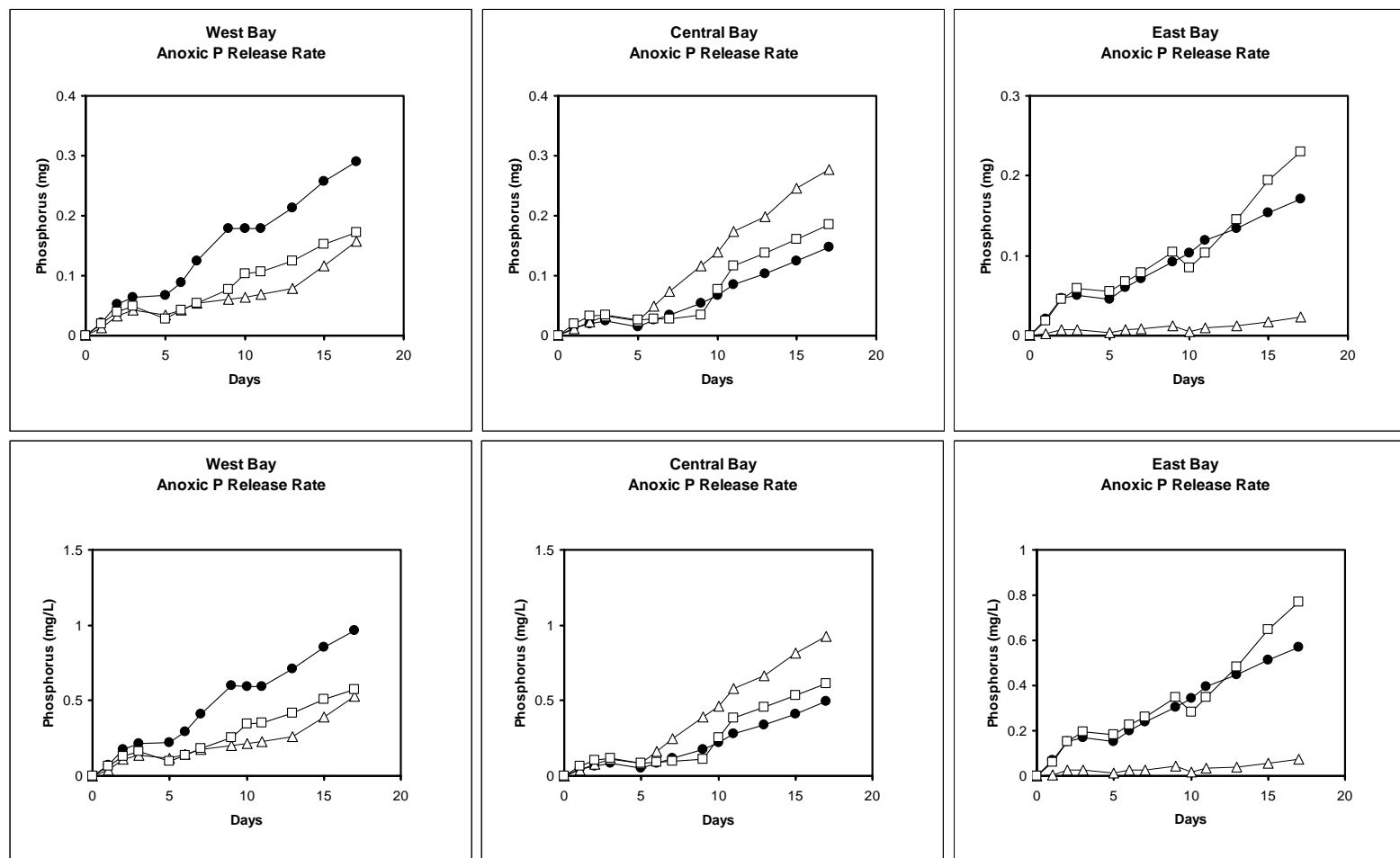


Figure 7. Changes in phosphorus (P) mass (upper panels) and concentration (lower panels) as a function of time for replicate sediment core incubation systems subjected to anoxic conditions. Please note scale differences between stations. Incubation temperature was 12 °C.

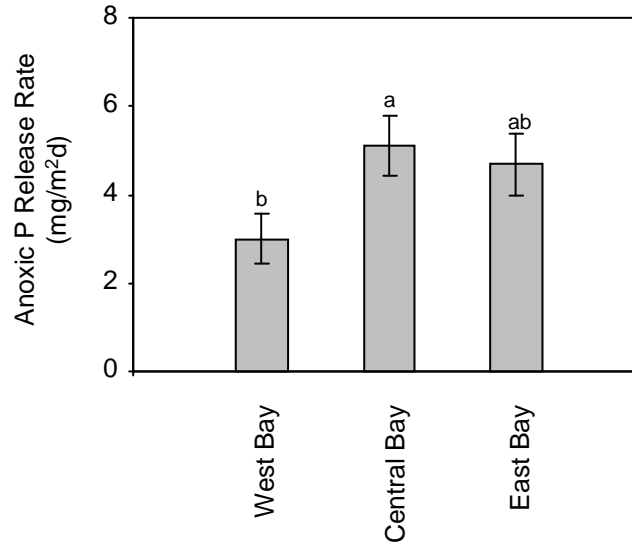


Figure 8. Mean (± 1 standard error) rates of diffusive phosphorus flux under anoxic conditions for sediment core incubation systems collected in West, Central, and East Bays of Lac Courte Oreilles. Incubation temperature was 12 °C. Different letters denote statistically significant differences based on ANOVA (Duncan-Waller; SAS 1994).

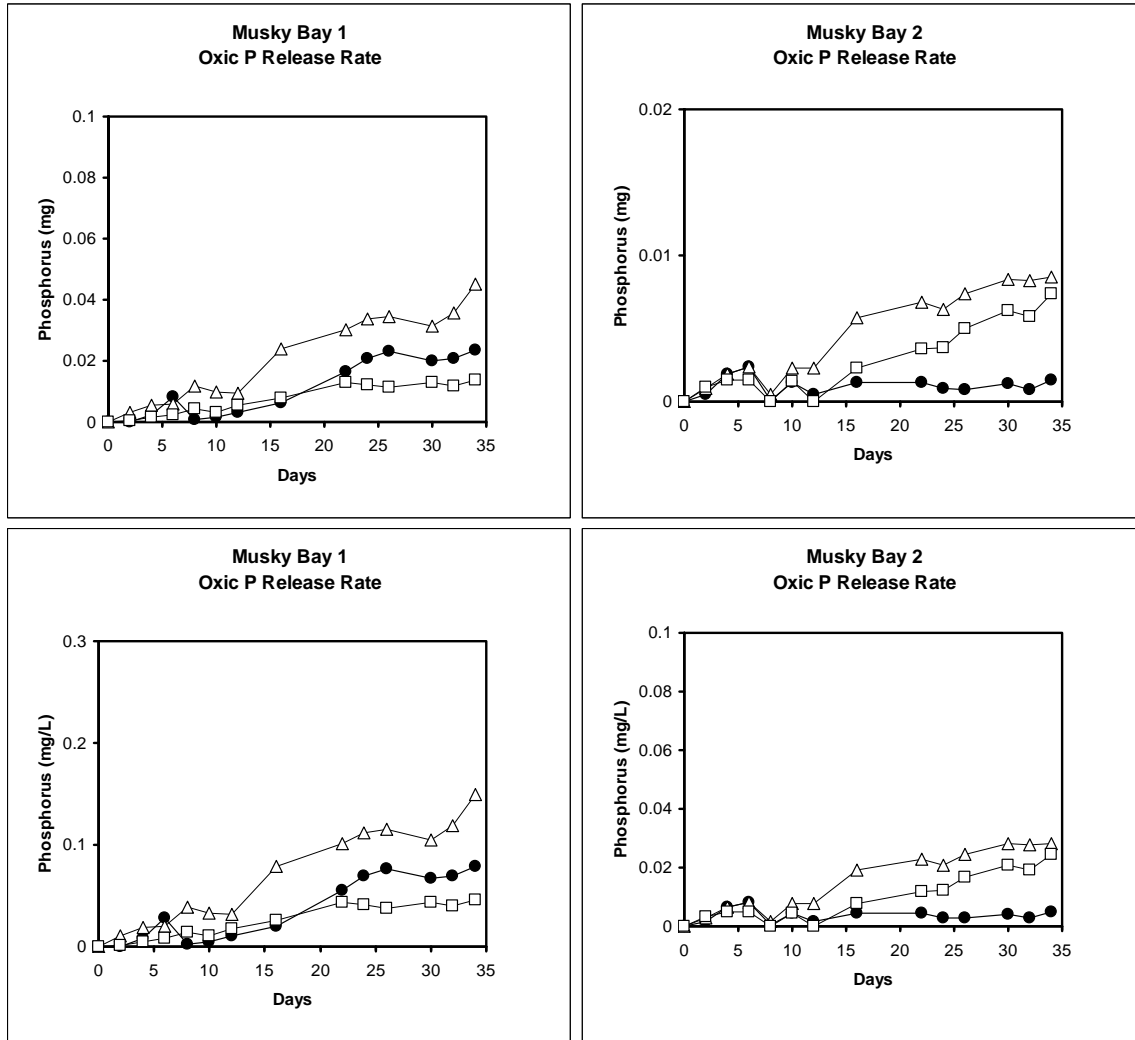


Figure 9. Changes in phosphorus (P) mass (upper panels) and concentration (lower panels) as a function of time for replicate sediment core incubation systems subjected to oxic conditions. Please note scale differences between stations. Incubation temperature was 25 °C

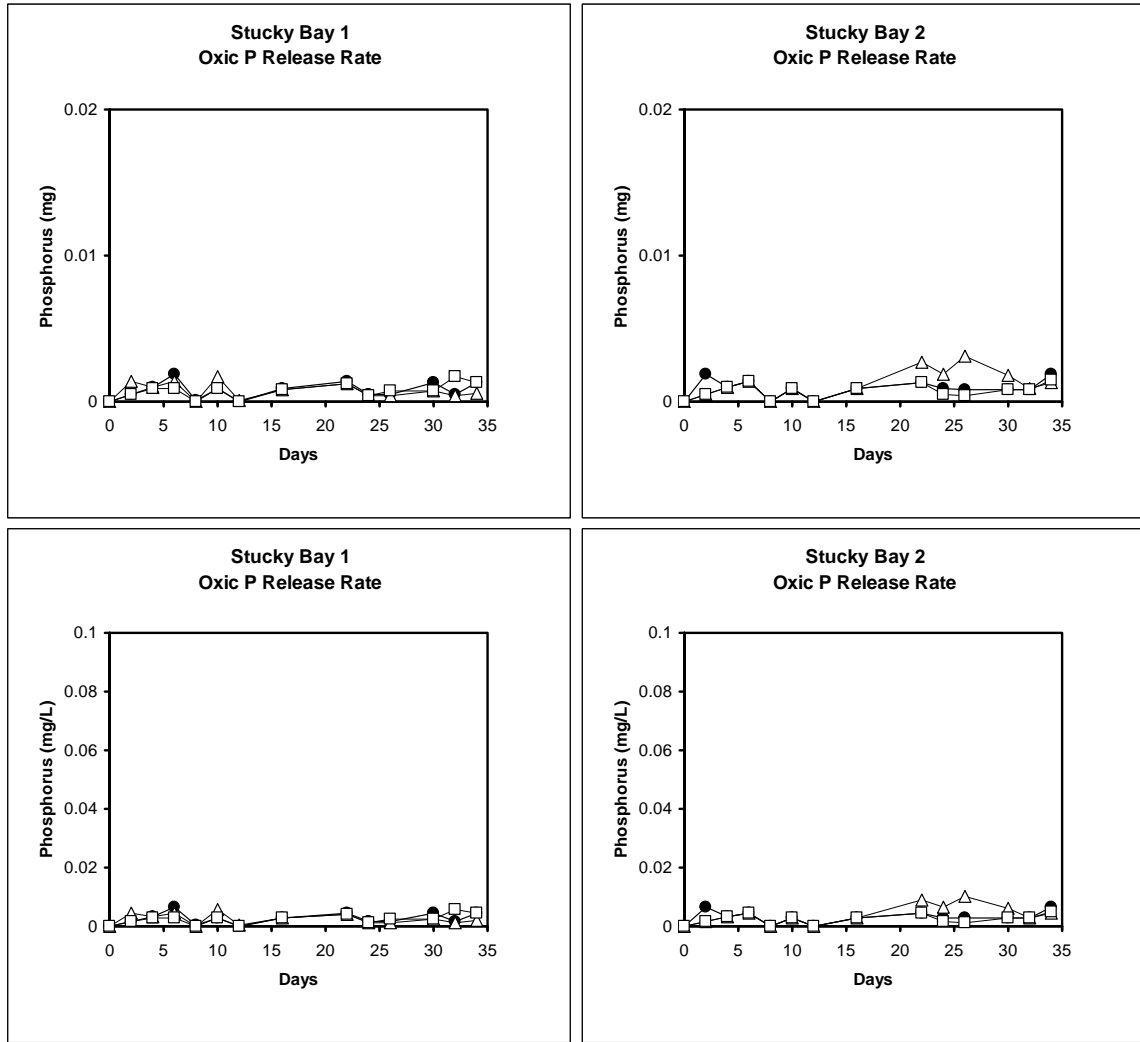


Figure 10. Changes in phosphorus (P) mass (upper panels) and concentration (lower panels) as a function of time for replicate sediment core incubation systems subjected to oxic conditions. Please note scale differences between stations. Incubation temperature was 25 °C

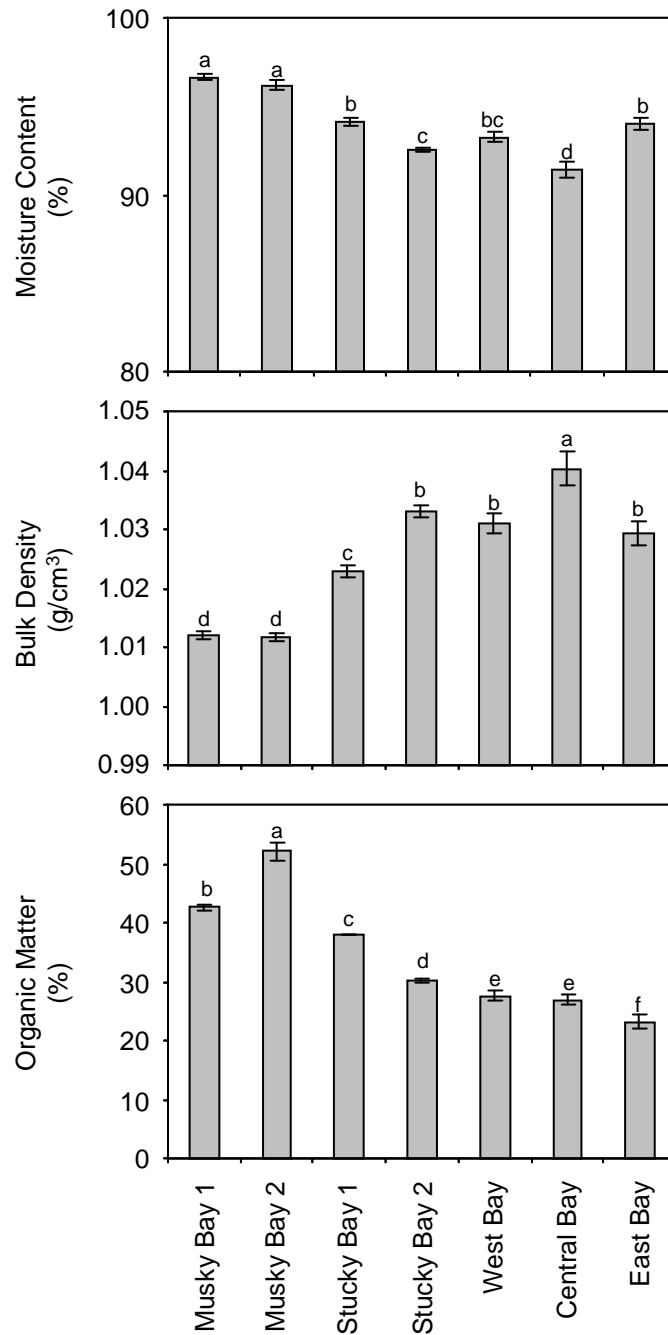


Figure 11. Variations in mean (± 1 standard error) sediment moisture content (upper panel), bulk density (middle panel), and loss-on-ignition organic matter content for the upper 10-cm sediment layer at various stations in Lac Courte Oreilles. Different letters denote statistically significant differences based on ANOVA (Duncan-Waller; SAS 1994).

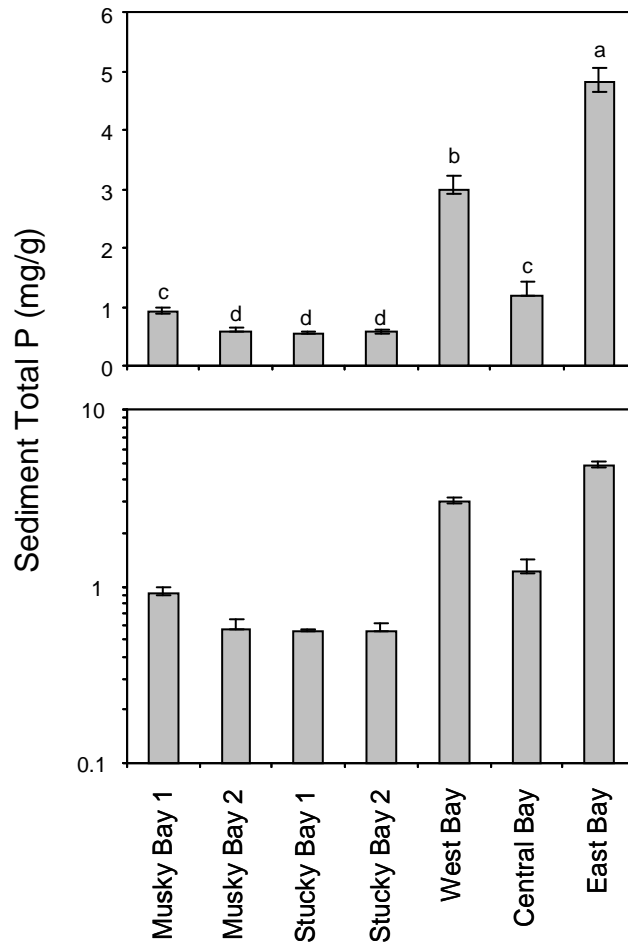


Figure 12. Variations in mean (± 1 standard error) sediment total phosphorus (P) for the upper 10-cm sediment layer at various stations in Lac Courte Oreilles. Please note the scale differences; the Y-axis is standard numerical scale on the upper panel and log-scale on the lower panel. Different letters denote statistically significant differences based on ANOVA (Duncan-Waller; SAS 1994).

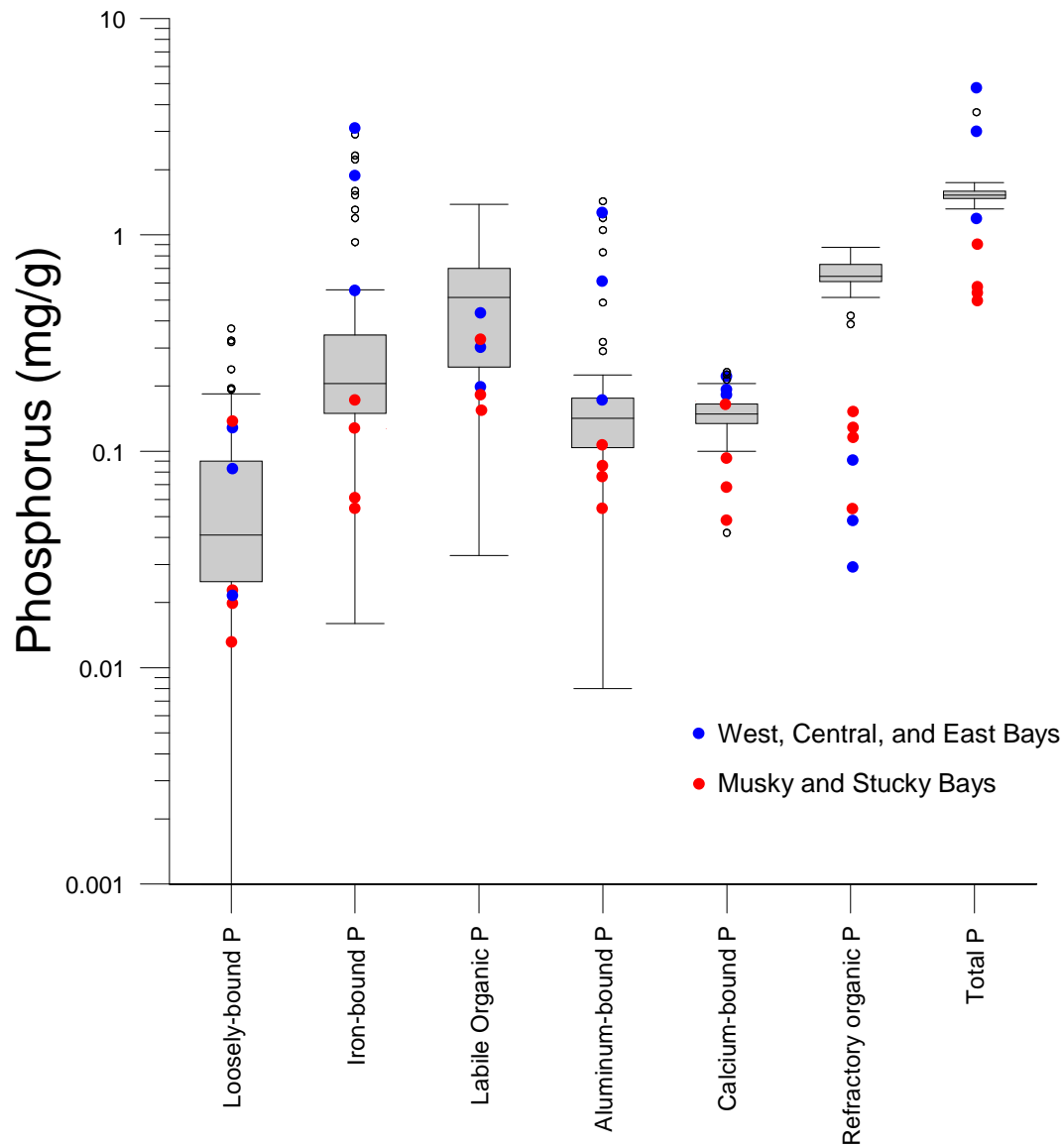


Figure 13. Box and whisker plots comparing various sediment phosphorus (P) fractions measured in the upper 10-cm sediment layer for stations in Lac Courte Oreilles with statistical ranges ($n=13$ lakes) for some lakes in the western region of Wisconsin (black circles represent outliers). Loosely-bound, iron-bound, and labile organic P are biologically-labile (i.e., subject to recycling) and aluminum-bound, calcium-bound, and refractory organic P are more inert to transformation (i.e., subject to burial). Please note the logarithmic scale.

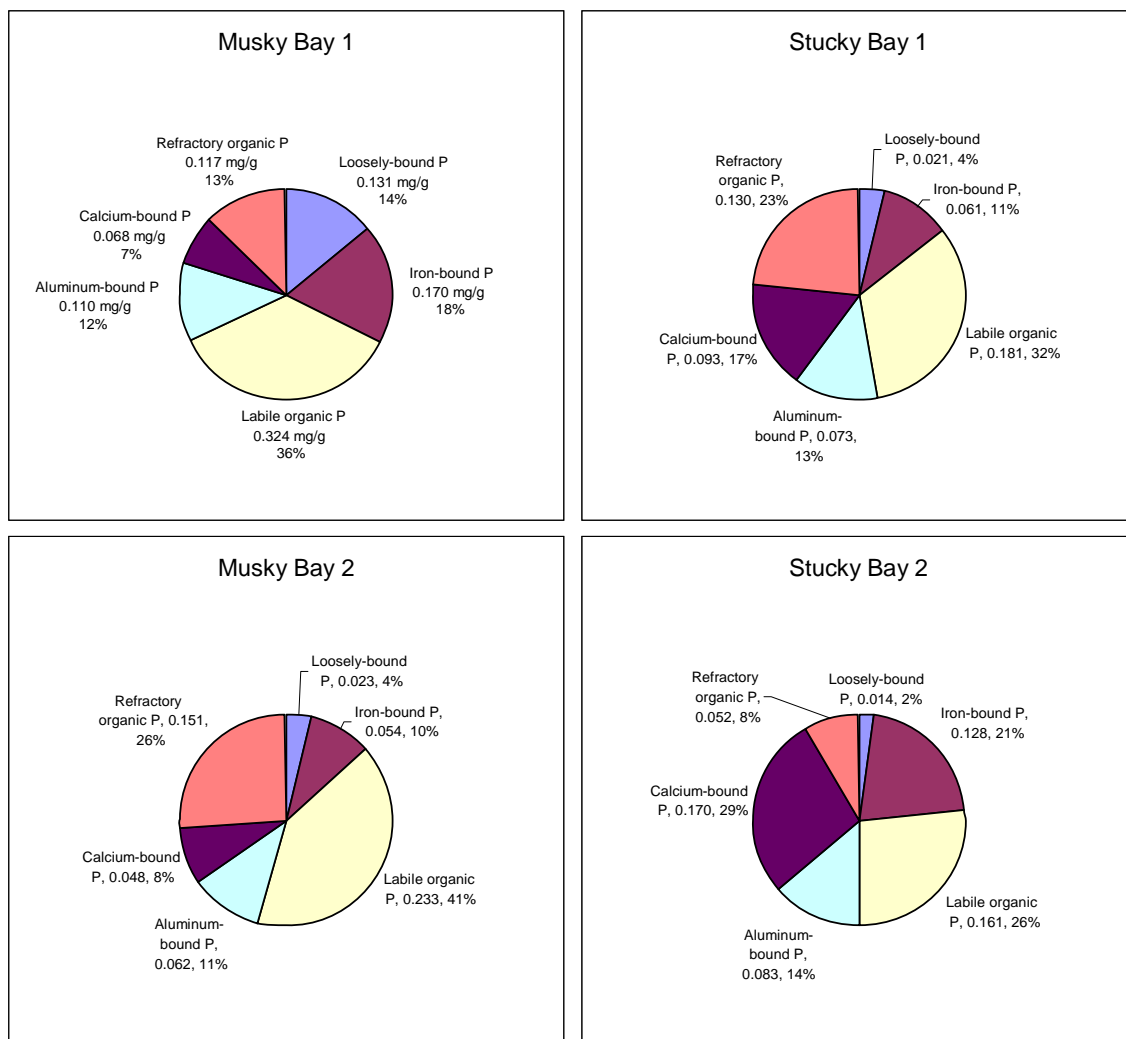


Figure 14. Total phosphorus (P) composition for sediment collected in shallow Musky and Stucky Bays of Lac Courte Oreilles. Loosely-bound, iron-bound, and labile organic P are biologically reactive (i.e., subject to recycling) while aluminum-bound, calcium-bound, and refractory organic P are more inert to transformation (i.e., subject to burial). Values next to each label represent concentration (mg/g) and percent total P, respectively.

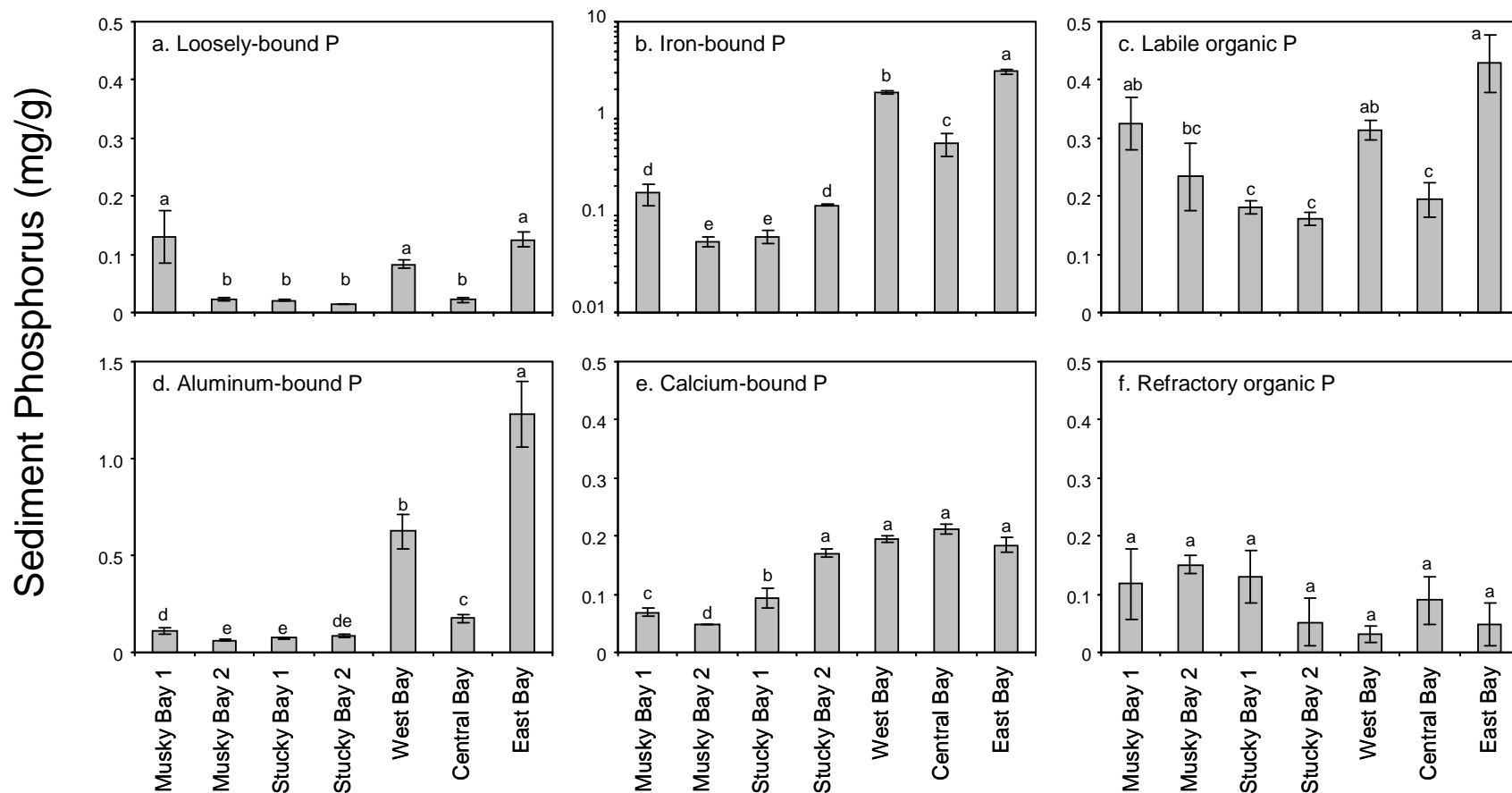


Figure 15. Comparison of mean (± 1 standard error) biologically-labile (loosely-bound, iron-bound, and labile organic P) and biologically refractory (aluminum-bound, calcium-bound, and refractory organic P) phosphorus (P) concentrations in the upper 10-cm sediment layer for various stations in Lac Courte Oreille. Please note the logarithmic scale for iron-bound P concentrations (panel b). Different letters denote statistically significant differences based on ANOVA (Duncan-Waller; SAS 1994).

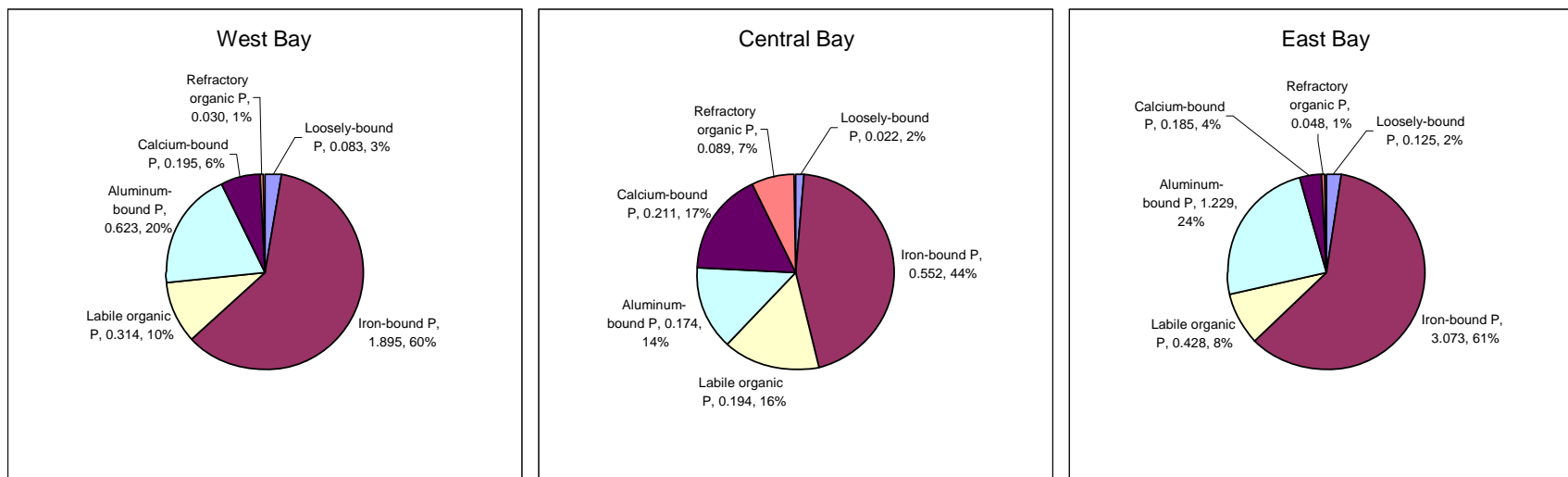


Figure 16. Total phosphorus (P) composition for sediment collected in the deeper West, Central, and East Bays of Lac Courte Oreilles. Loosely-bound, iron-bound, and labile organic P are biologically reactive (i.e., subject to recycling) while aluminum-bound, calcium-bound, and refractory organic P are more inert to transformation (i.e., subject to burial). Values next to each label represent concentration (mg·g⁻¹) and percent total P, respectively.

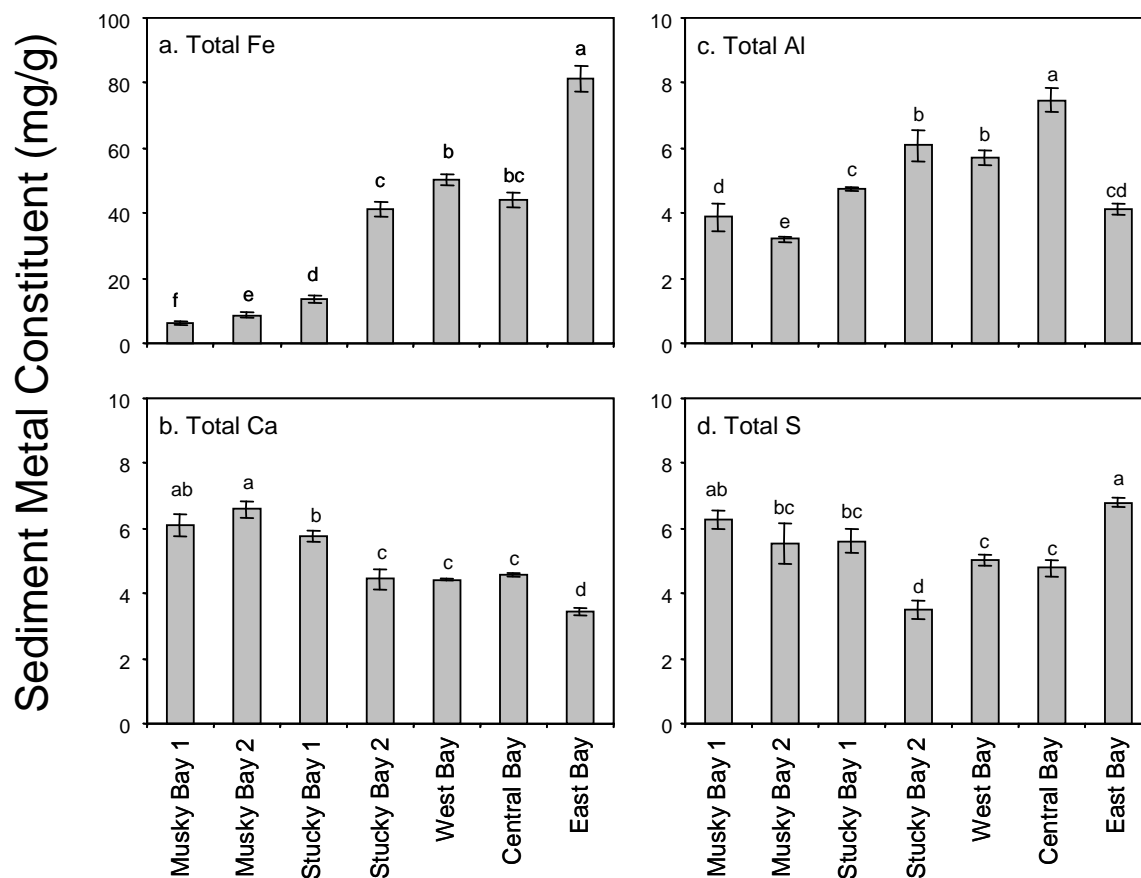


Figure 17. Variations in mean (± 1 standard error) sediment total iron (Fe; upper left panel), total calcium (Ca; lower left panel), total aluminum (Al; upper right panel), and total sulfur (S; lower right panel) for the upper 10-cm sediment layer at various stations in Lac Courte Oreilles. Different letters denote statistically significant differences based on ANOVA (Duncan-Waller; SAS 1994).

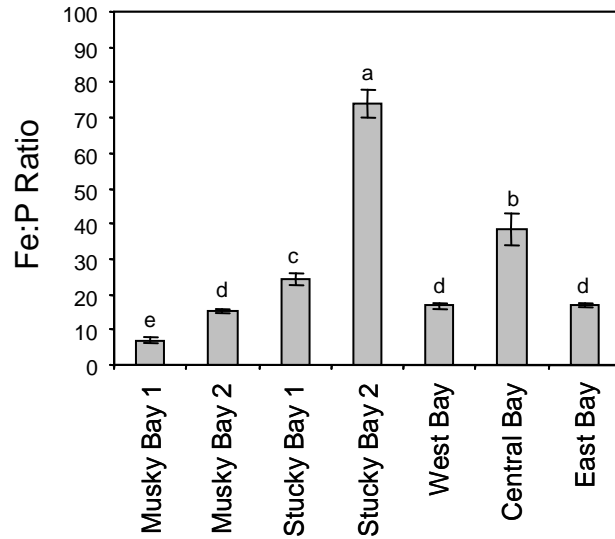


Figure 18. Variations in the mean (± 1 standard error) sediment total iron:total phosphorus ratio (Fe:P) for the upper 10-cm sediment layer at various stations in Lac Courte Oreilles. Different letters denote statistically significant differences based on ANOVA (Duncan-Waller; SAS 1994).

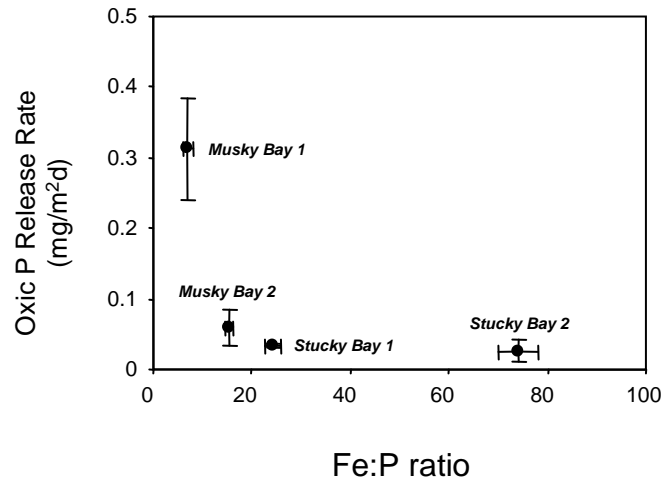


Figure 19. Relationships between the oxic P release rate and the total iron:phosphorus (Fe:P) ratio.

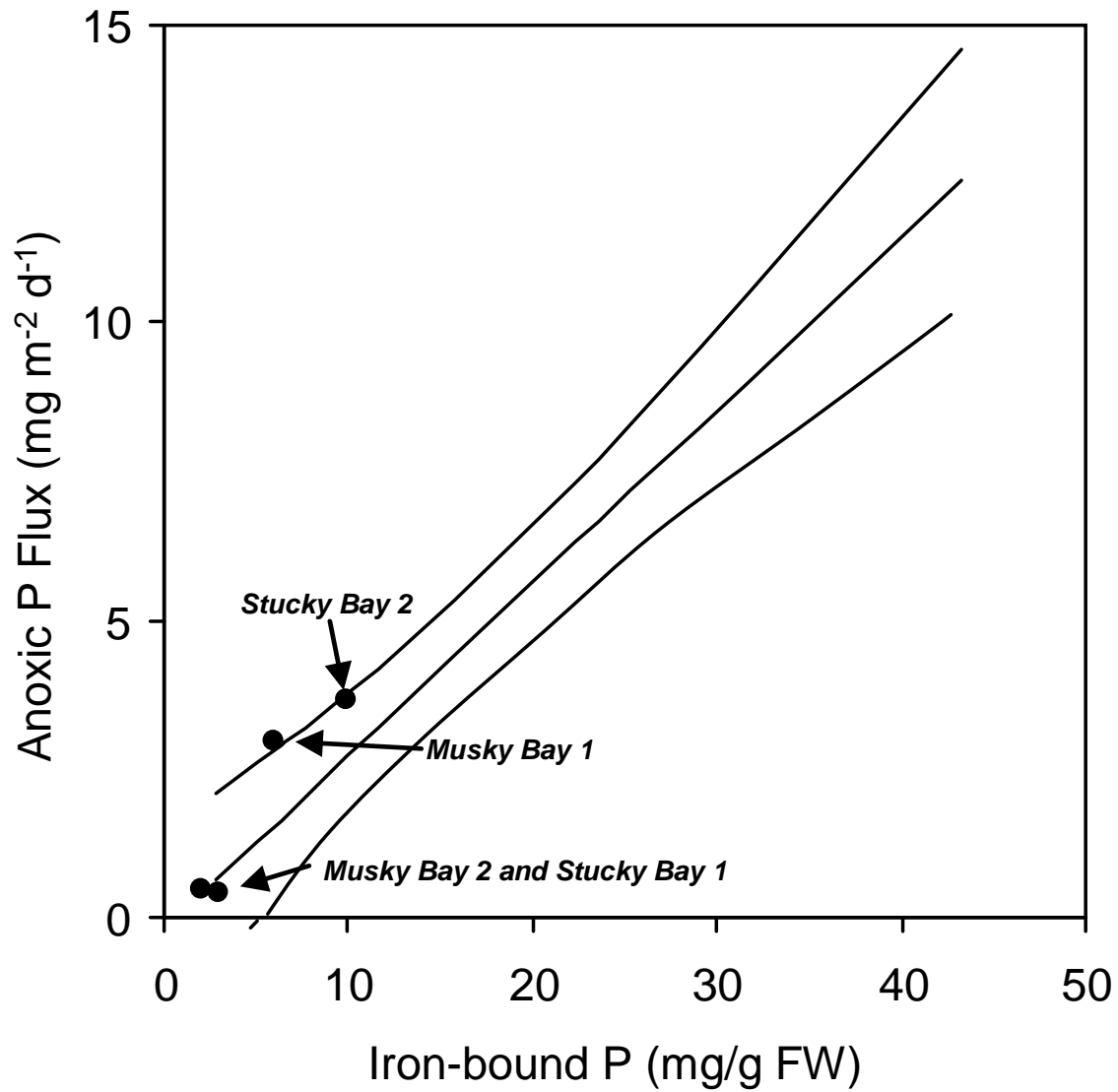


Figure 20. Relationships between iron-bound phosphorus (P; mg/g fresh sediment mass) and rates of P release from sediments under anoxic conditions. Regression line and 95% confidence intervals from Nürnberg (1988) are shown for comparison.

Appendix F



Blank page



Lac Courte Oreilles Lake Management Plan

*C. Bruce Wilson
February 21, 2011*



Acknowledgements

I thank WDNR Project Manager Jim Kreitlow for his advice during the project and his document review assistance. I also thank the Courte Oreilles Lakes Association for their support and encouragement, particularly Gary Pulford who has been the grant coordinator, project lead and tireless advocate for Wisconsin lakes and streams. I thank Dan Tyrolt and the Lac Courte Oreilles Band of Ojibwe Conservation Department for their support, guidance and data collected over the past 14 years, without which, this report would not have been possible. The Lac Courte Oreilles Tribal Conservation Department's lake and stream monitoring programs are exceptional. Sawyer County's technical support, particularly Dale Olson, was greatly appreciated. Lastly, I thank Rob Engelstad and Gary Pulford for Secchi disk volunteer monitoring and all of the residents who participated in the LCO Economic Survey.

Report Section	Page
Executive	
Summary.....	3
Introduction	8
Outstanding Resource Waters	9
Fisheries	10
Lac Courte Oreilles Morphometric Characteristics	13
Lac Courte Oreilles Watershed Characteristics	16
Hydrologic Budget	
Climatological Summary	19
Precipitation	20
Temperature and Evaporation	23
Surface Water Hydrology	
Flow network	24
Regional runoff and LCO Outlet Volumes	26
Lake Mixis	28
Lake Data Analysis	
LCO data	32
Variable Climate	37
Modeling	38
Modeling Results	41
Trend Detection	45
Conclusions	46
Recommendations	47
References	50
Appendices	
Appendix A. Lake Map and Data	
Appendix B. Watershed Characteristics	
Appendix C. Lake data plots	
Appendix D. BATHTUB Modeling Summary Plots and Tables.	

Executive Summary

This report and its companion effort “Lac Courte Oreilles Economic Survey and Assessment”, have been prepared for the Wisconsin Department of Natural Resources via Lake Planning Grants awarded to the Courte Oreilles Lakes Association (COLA).

Lac Courte Oreilles (LCO) with its four main bays and Little Lac Courte Oreilles, are regionally exceptional lakes in terms of their size, water quality, including LCO’s historical two story fishery and general habitat. These same qualities make these lakes sensitive to: (1) discharges from cranberry operations; (2) watershed land uses that increase loads of phosphorus, sediment and organic-laden waters; (3) effects of variable climate; and (4) non-native invasive infestations such as curly leaf pondweed. All of these factors mean LCO will be extremely sensitive to phosphorus (P) and organic loading (e.g. turbid runoff from urban and agricultural sources) that can induce internal lake sediment P recycling mechanisms, and hence, several actions are being recommended. If degraded, rehabilitation measures will be extremely difficult and prohibitively expensive to implement.

Variable climate has been noted over the past two decades, going from relatively wet years (1996 and 2002) to drought conditions (2005-2009), intense storms, reduced stream flows and longer growing seasons. Over the past 40 years, there has been a declining regional runoff pattern (about 18% less) for the Chippewa River at Winter, WI. Recent years have seen a dramatic increase in the number of tornados with tornados noted in Wisconsin 46 including the rare November 22, 2010 and about 125 noted in adjacent Minnesota in 2010.

The ‘Northwood Charm’ is a significant, in a business sense, ‘product’, of the region. Competing for and sustaining future travel and tourism will be dependent upon maintaining the quality of the product, otherwise discretionary travel dollars will be spent elsewhere. And in a long-term business sense, this will require re-investing in forested land areas and restoring and protecting the water assets that cover 84% of the LCO watershed. The intensity of stormwater runoff and future development pressures will require additional proactive operation and maintenance rather than an ‘it will take care of itself’ approach.

Key challenges include maintaining forests & waters in an increasingly variable climate with droughts, fires, wet periods, intense storms (damage, erosion and shock loads to lakes and streams) and longer growing seasons. A balance must be achieved between limiting the amount of pollutants flowing into waters and conflicting water uses (e.g. cranberry discharges and development) so the lakes stay healthy and maintain present beneficial uses. This will mean (1) working with the owners to eliminate cranberry operation discharges; (2) enforcement of existing land use ordinances and minimizing variances for nonconforming structures and practices (Losing our lakes: Part 1. Rules skirted and lakes under attack, Minneapolis Star Tribune, July 6, 2010); (3) buffering 100% of the LCO shorelands; (4) installation, and maintenance and oversight of agricultural and forestry Best Management Practices (BMPs); and (5) adopting new low impact development ordinances to treat stormwater from new development runoff on site. Stormwater volume control standards have the most promise of minimizing stormwater runoff by requiring new developments to treat runoff from impervious surfaces on-site via infiltration, storage, or reuse.

As land is converted from forest into urban or agricultural land uses, there will be an increased loss of nutrients and sediments to the lakes. For comparison, present day average

watershed total phosphorus in runoff typically contains very low levels (on the order of 10-40 parts per billion) versus much higher concentrations in agriculture and urban runoff (on the order of 150 – 600 parts per billion). The cumulative effects of the pounds of phosphorus reaching LCO is significant as each part per billion increase in LCO average summer total phosphorus can result in a loss of about one foot of average summer water clarity, particularly in the deep LCO bays. For example, increasing average summer total phosphorus from 9 to 15 ppb can translate into a loss of transparency of about 6 feet (e.g. average Secchi would drop from ~18 feet to 12.5 feet) based on regional phosphorus:Secchi relationships.

In sum, variable climate, as defined in this Plan, can be expected to generally favor lake degradation patterns unless additional management actions are taken. The non-native infestations, such as Curly Leaf Pond Weed (CLPW) will be a growing issue. New challenges from other infestations of LCO's lands and waters will require vigilance, monitoring and actions.

Water Quality Goals for Lac Courte Oreilles

For the purpose of providing definitive objectives that will drive COLA lake management strategies and activities, COLA should establish the following water quality goals for Lac Courte Oreilles:

Classification and One Lake Determination

a. Classification

Pursuant to Wisconsin Rule NR 102, Lac Courte Oreilles is: 1) a stratified two story lake/fishery and 2) is classified as an Outstanding Resource Value (ORV) water. COLA has and will continue to undertake lake management strategies and activities that will maintain these classifications.

The anti-degradation provisions of state and federal statutes and rules will be relied upon to serve as the legal framework that will drive COLA lake management actions intended to maintain the current NR 102 classifications.

b. One Lake Determination

COLA intends that the NR 102 classifications and associated applicable water quality criteria, standards and the goals set forth in this Lake Management Plan be uniform equally applied to all the natural bays of LCO. To assume that LCO bays are separate upland lakes that drain into LCO via streams, ignores inter-bay advection and dispersive mixing. Assigning higher upland P standards to Musky Bay could also result in assignment of the same standards to Stuckey Bay and perhaps NE Bay, that will directly cause degradation of the open-water connected deeper bays. There can be no effective P management in west, central and east bays without control of smaller bay phosphorus levels. Hence, COLA will resist any efforts or interpretations that attempt to distinguish one LCO bay from another for the purposes of setting and applying water quality classifications, criteria, standards and goals. Lac Courte Oreilles is one lake and must be managed accordingly.

Total Phosphorus

c. Lac Courte Oreilles

The long term total phosphorus goal for all natural bays of LCO is 10 +/- 2 parts per billion (ppb). Achieving the long term goal will rely upon anti degradation management actions.

d. Musky Bay

As a result of excessive phosphorus loading, Musky Bay has much higher total phosphorus concentrations than the rest of LCO. To reverse the degradation of Musky Bay will require establishment of both short and long term total phosphorus goals for the bay. Therefore, the short-term total phosphorus goal for Musky Bay is 20 ppb. COLA intends to take those lake management actions necessary to achieve the short term goal by 2016. The long-term goal for total phosphorus for Musky Bay is 10+/-2 ppb.

Lac Courte Oreilles Lake Management Plan

In order to achieve the specified water quality goals of maintaining LCO's current water quality into the future, COLA must address five management areas over the coming decades. The five management areas are: 1) cranberry discharges; 2) changing land uses in the LCO watershed; 3) LCO shore land development and buffer areas; 4) invasive species management; and 5) lake and stream monitoring. COLA intends to take the following specific actions to address the five challenge areas.

1. Cranberry Discharges

- a. COLA will work with the three cranberry growers on LCO to eliminate their discharges of organic and phosphorus loading to LCO.
- b. To reduce sediment phosphorus recycling in Musky Bay and to a lesser extent in Stuckey Bay, COLA will investigate and determine if dredging and/or alum or iron chemical treatment would be effective in reducing sediment phosphorus recycling in the two bays.
- c. COLA will work with the LCO Band of Ojibwe and WDNR to develop and implement a plan of action to re-establish muskellunge spawning habitat in Musky Bay.

2. Changing Land Use in the LCO Watershed

- a. COLA will evaluate formation of a lake management district to advance long-term improvement and protection of LCO water quality and associated economic resources.
- b. COLA will seek to acquire lands on the south side of LCO's east bay where intensive agriculture is practiced within the LCO direct drainage area.
- c. COLA, working closely with the LCO Band of Ojibwe will seek to acquire land and easements along Osprey Creek. Osprey Creek drains through the heart of present-day and likely future new urban and agricultural areas, land use in this part of the LCO watershed will play a prominent part in the future of LCO water quality.. Maintenance of wetlands and creek buffer areas are a high priority with COLA.
- d. COLA will work with other affected lake associations, Sawyer County, LCO Band of Ojibwe, WDNR and land owners to implement forest Best Management Practices (BMPs) within the LCO watershed.
- e. COLA will work with other affected lake associations, Sawyer County, LCO Band of Ojibwe and WDNR to monitor and advance agricultural BMPs for row

crop and animal operations within the LCO watershed (particularly operations on the west side of LCO), including providing cost share for innovative approaches that may not be covered by existing state and federal programs.

- f. Runoff from new development can be largely prevented with the adoption of stormwater volume control practices via the use of low impact development techniques and better site designs. COLA will work with other affected lake associations, Sawyer County to adopt a county low impact development ordinance that applies to the LCO watershed. The county ordinance should include the following requirements:
 - i. The first 1.25 inches of runoff from new development impervious surfaces should be required to be treated on site. Nearly two-thirds of the LCO watershed soils have reasonably high infiltration capacity (e.g. Hydrologic Soil Group A & B soils). Using these soils for infiltration & on-site treatment can be accomplished by a variety of techniques such as pervious pavers/pavement, native vegetation and rain gardens while placing more impervious surfaces on the lesser infiltrating C and D soils.
 - ii. New developments should be required to minimize soil compaction practices and in D soils, minimal soil disturbance practices should be required during construction along with requiring better site designs that preserve forest and stream buffer areas.

3. LCO Shoreland Development and Buffer Areas:

- a. COLA will support the Sawyer County shore land development ordinances by actively reviewing and taking a position on all variance requests that affect LCO.
- b. COLA will work with Sawyer County and WDNR to achieve establishment of shore land buffer zones on 100% of LCO lake shore properties. Continuing education of shore land owners of the importance of shore land buffering is a high priority for COLA.
- c. COLA will work with Sawyer County to develop periodic surveys of all LCO's on-site treatment systems for compliance with septic system requirements.

4. Invasive Species Management:

- a. COLA will continue to work with the LCO Band of Objibwe, Sawyer County, and the WDNR to carry out herbicide treatments to control the curly leaf pondweed infestations in LCO.
- b. COLA will maintain the Clean Boat Program. Additional control measures will be needed to prevent and minimize new invasive infestations such as Viral Hemorrhagic Septicemia and zebra mussels. Measures to be considered may include altering public boat landings to have pre-launch check points with bill board instructions. In addition COLA will investigate new approaches such as consideration of boat washing stations above the access ramps for incoming and outgoing boat cleaning.
- c. COLA will work with Sawyer County via the forest management plan and assist in tracking of forest invasive species such as the European night crawler Lumbricus terrestris. This night crawler can alter forest floor conditions dramatically causing increased water and nutrient runoff. Sawyer County ordinances may also be considered prohibiting disposal of bait night crawlers.

5. Trend Detection Lake and Stream Monitoring

- a. COLA will consider additional monitoring of lake outlet and primary inlet stream volumes and sampling to better define annual loading rates, water flow patterns and better estimate the magnitude of groundwater influence on LCO. Detailed monitoring recommendations have been provided in the Recommendations of this Lake management Plan
 - i. Contract with the USGS to begin gauging LCO's outlet and Osprey Creek in cooperation with the LCOCD and local partners. Other water monitoring recommendations have been detailed in the last part of the Plan.
- b. COLA should continue cooperative efforts with the Lac Courte Oreilles Band of Ojibwe and Sawyer County and the WDNR to identify and protect vulnerable wetlands, streams and system storage as a high priority.
- c. Work with other lake associations in the watershed to have Secchi disk transparency monitoring conducted on each lake, particularly Durphee, Osprey, Grindstone, Sand, and Whitefish Lakes.

Introduction

Courte Oreilles Lakes Association (COLA) is focused on efforts to reduce pollution, particularly phosphorus pollution, protect and restore critical habitat, research water quality issues and protect the water quality of Big and Little LCO. This report and its companion effort “Lac Courte Oreilles Economic Survey and Assessment” have been prepared for the Wisconsin Department of Natural Resources by Lake Planning grants awarded to the Courte Oreilles Lakes Association (COLA).

Lac Courte Oreilles (LCO), located in Sawyer County, is Wisconsin’s eighth largest natural lake (Pratt, 1977), has been classified as an oligotrophic lake (Garrison and Fitzgerald, 2005), covering 5,039 acres and represents about 9% of the County’s lake acreage. The LCO watershed is located in the Northern Lakes and Forest ecoregion and lies in Sawyer County with a small portion extending into Washburn County. Native soils consist of sandy loam, sand and silts with native vegetation consisting of deciduous/hardwood and coniferous forests. Forests and water/wetland land uses cover over 84% of the LCO watershed with agriculture and urban land uses comprising about 4%, each, of the watershed.

Presently, there are three operating cranberry bogs that withdraw water from and discharge water to Stuckey Bay, Musky Bay and East bay of Lac Courte Oreilles, ranging in size from approximately 3 to 39 ha. Collectively the three operations cover an area of about 85 ha (or 212 acres). The two largest operations discharge to Stuckey Bay (about 39 ha or 97 acres) and Musky Bay (about 32 ha or 79 acres) with a smaller operation of about 7.5 acres discharging to the East bay. The two largest cranberry operations began about 1939 with expansions occurring between 1950 and 1962 and again in Musky Bay between 1980 and 1998 (Fitzpatrick et al, 2003).

Annual precipitation for the area averages about 34.5 inches with about one-half occurring in the growing season of June through September. Winter snow fall has typically been about 55 inches with considerable variability as regional values have varied from about 46 inches to 76 inches. Substantial wet and dry period variability is occurring with recent dry years (e.g. 2005 with 2009 with ~ 6+ inches below average rainfall) resulting in very low surface water flows. There are very few stream continuous flow monitoring stations in Northwest Wisconsin. The closest two stations were summarized and used as the basis for developing flow estimates for LCO and included : Chippewa River at Winter and Namekagon River at Leonards, Wisconsin. The Chippewa River (at Winter) had very low flows or about 3rd percentile in 2009. In contrast, 1996 had peak runoff (high flows) for the 40 year period.

LCO is a soft water (low alkalinity) lake with four main bays stretching approximately six and one-half miles in a predominantly southwest to northeast orientation. LCO has an overall mean depth of about 34 feet, a maximum depth of 92 feet and a shoreline length of 25.4 miles. Two of the lake’s main tributaries, Grindstone and Osprey Creeks enter on the east bay along with Spring Creek on the south side. Whitefish Lake discharges into the southern side of central bay. The lake outlets from the east bay through a short passage to Little Lac Courte Oreilles, then to the Billy Boy Flowage, the Couderay River and then the Chippewa River. The outlet on Billy Boy Flowage is controlled by a dam with a head of about 3 m (10 feet) that raised . raised historical water levels in the Billy Boy flowage by about 2 m (7 feet). Today, water levels in LCO , Little LCO and Billy Boy Flowage are quite similar (Fitzpatrick et al, 2003). Ultimately Lac Courte Oreilles flows into the Mississippi River at Lake Pepin.

Most water flows into and out of LCO occur through the east bay - except for bay-to-bay wind mixing. With much less water runoff reaching other bays, the central and west bays have much longer water residence times (e.g. estimated 5 and >100 years, respectively versus the east bay's estimated residence time of ~ 2 years during dry year of 2009). This will tend to make the west and central bays more sensitive to runoff from direct drainage areas (shore land development, cranberry discharges, agriculture, and other urban development).

The LCO watershed at the lake outlet, covers 68,990 acres and includes other significant Wisconsin natural lakes: Round Lake (3,054 acres) and Grindstone Lake (3,116 acres) that drain into the east bay; and (2) Sand Lake (928 acres) and Whitefish Lake (786 acres) that drain into the central bay. The eastern ~half of the lake is located in the Lac Courte Oreilles Indian Reservation. LCO has an abundance of sports fisheries and is considered a two story fishery (meaning it supports both cold, cool and warm water fish species). Being a popular recreational resource it draws visitors from Wisconsin, Minnesota, Illinois and states as far away as Hawaii (Wilson, 2010).

There are no municipal wastewater discharges into streams or lakes of the watershed, however, there are three cranberry operations with pipe discharges directly into LCO Bays: two discharges into Musky Bay and Stuckey Bay and one into east bay. In the past, Musky Bay, located in the southwestern portion of the Lake, supported musky spawning/rearing habitat and the legacy crop, wild rice back in the ~1920's.

Now, the nuisance exotic aquatic Curly leaf pondweed and algal masses can cover significant portions of Musky Bay. The US Geological Survey (Fitzpatrick et al, 2003) collected and assessed sediment cores from Musky Bay, Lac Courte Oreilles, and from surrounding areas and determined the water quality of Musky Bay has degraded during the last ~25 years with increased growth of aquatic plants and the onset of a floating algal mats. LCOCD and COLA are working with Sawyer County and the Wisconsin Department of Natural Resources (WDNR) to control curly leaf pondweed infestations in Musky Bay via chemical treatments. Curly leaf pondweed has spread beyond Musky Bay to other parts of the lake, that at this writing include Stuckey Bay, Barbertown Bay and the Grindstone channel.

Outstanding Resource Waters

Wisconsin's Outstanding Resource Waters (ORWs) include Grindstone Creek (trout), Grindstone Lake, Round Lake, Sand Lake, Whitefish Lake, Lac Courte Oreilles tributary at R39N R8W S5 and Lac Courte Oreilles. The following definition excerpts from the WDNR are provided:

- ~~Wisconsin~~ Wisconsin has designated many of the state's highest quality waters as Outstanding Resource Waters (ORWs) or Exceptional Resource Waters (ERWs). Waters designated as ORW or ERW are surface waters which provide outstanding recreational opportunities, support valuable fisheries and wildlife habitat, have good water quality, and are not significantly impacted by human activities. ORW and ERW status identifies waters that the State of Wisconsin has determined warrant additional protection from the effects of pollution. These designations are intended to meet federal Clean Water Act obligations requiring Wisconsin to adopt an ~~antidegradation~~ "antidegradation" policy that is designed to prevent any lowering of water quality – especially in those waters having significant ecological or cultural value."

- ORWs typically do not have any point sources discharging pollutants directly to the water (for instance, no industrial sources or municipal sewage treatment plants), though they may receive runoff from nonpoint sources. [Author's note nonpoint sources include crop/animal agricultural runoff and shoreland impervious surface/compacted soils runoff.] New discharges may be permitted only if their effluent quality is equal to or better than the background water quality of that waterway at all times—no increases of pollutant levels are allowed.
<http://dnr.wi.gov/org/water/wm/wqs/orwerw/> downloaded by CBW on 11/10/10.

Public Access

There are two public accesses on LCO (Appendix) with the WDNR site located on Highway K on Chicago Bay. This site has a double-wide concrete boat ramp, a barrier-free roll-out boarding dock, pit toilets, and a parking area for 50 car-trailer units

Fisheries

LCO is a two story fishery (Pratt, 1977) that has supported cold water species (trout), cool water species (tulibee) and warm water sports fisheries such as walleye, bass, and muskellunge. A recent WDNR strategic planning effort summarized in the document, "Fishery Management Plan Lac Courte Oreilles Sawyer County, Wisconsin" was completed by Pratt and Neuswanger (2006). This effort defined sports fisheries management strategies for muskellunge, smallmouth bass, walleye, black crappie, and northern pike.

The lake's littoral substrates are comprised of sand, gravel and rock except where replaced by soft organic muck in Musky and Stuckey Bays. Musky Bay was named for its historical significance as a muskellunge spawning area. In recent years, Musky Bay does not serve as a viable habitat for musky spawning due to the excessive organic matter and low oxygen concentrations along the bottom substrates (Pratt and Neuswanger, 2006). The LCO muskellunge genetic strain, widely propagated in Wisconsin and Minnesota waters, has been dramatically reduced in LCO due to loss of spawning habitat in Musky Bay and the introduction of the northern pike. LCO fish community characteristics were summarized by Pratt and Neuswanger with common species including smallmouth bass, yellow perch, bluegill and cisco.

Also noted to inhabit LCO were whitefish, white sucker, greater redhorse, bluntnose minnow, spottail shiner, blacknose shiner, and other small cyprinid species; trout perch, log perch, johnny darter, rainbow darter, and other small darter species; pumpkinseed, rock bass, longear sunfish, tadpole madtom, bullheads (black, yellow, and brown); slimy sculpin, longnose gar, and rainbow trout and brown trout. The later were documented by Pratt (1977) in 1976 fish surveys of LCO.

Studies have linked hypolimnetic oxygen depletion and phosphorus concentrations. Nordin (1986) proposed a range of surface average summer total phosphorus 5-15 ug P/L (or parts per billion or ppb) for the protection of coldwater fisheries. He noted that hypolimnetic oxygen depletions began when total phosphorus exceeded 10 ppb which is often used as the upper boundary for oligotrophy, along with chlorophyll-a concentrations less than 2 ppb and summer mean Secchi transparency of 4.5 m (14.8 feet). Two story fishery lakes generally have average summer phosphorus less than 15 ppb with changes occurring when lakes exceed 10 ppb.

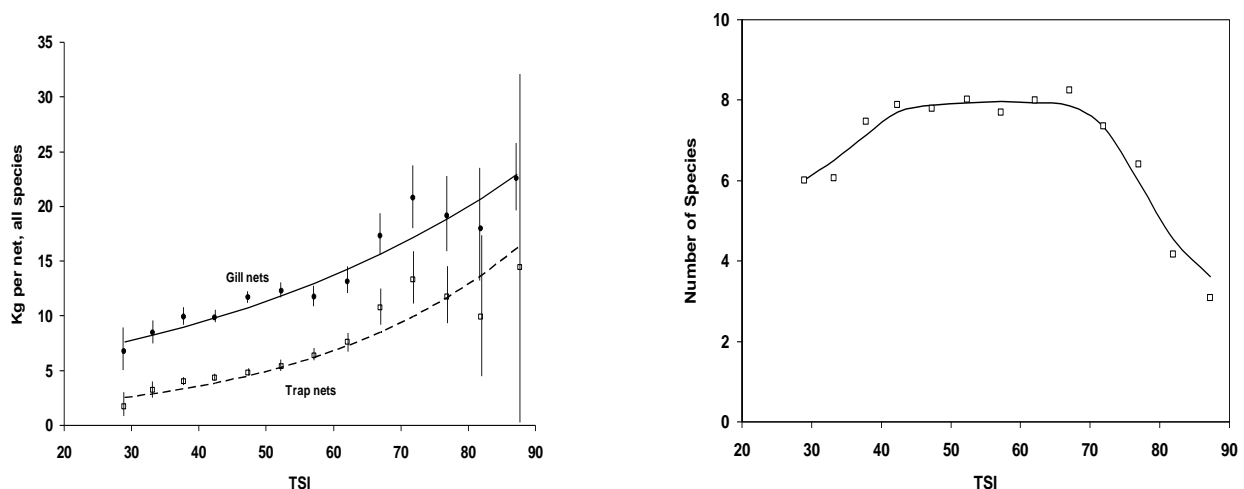
The influence of lake water quality upon fisheries has been examined by Schupp (1992), Schupp and Wilson (1993) as they compared the relative abundance and presence of various species and water quality as represented by trophic status index or TSI. The coldwater fishes: lake trout, whitefish and cisco exhibited peak abundance over a range of about 30-40 TSI (TP ~ 6-12 ppb). Lake trout were generally not observed in lakes with greater than ~17 ppb. Walleyes were abundant across a wider range of trophic state with abundance peaking at a TP range of about 12 – 24 ppb. Schupp and Wilson (1993) suggested that the best indicators of water quality are two of the three bullhead species with yellow bullheads found in the highest numbers in lakes with clear water. Black bullheads reach their highest abundance in very turbid eutrophic waters.

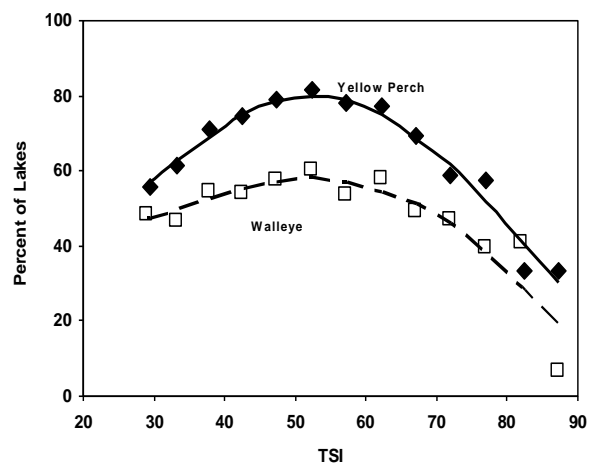
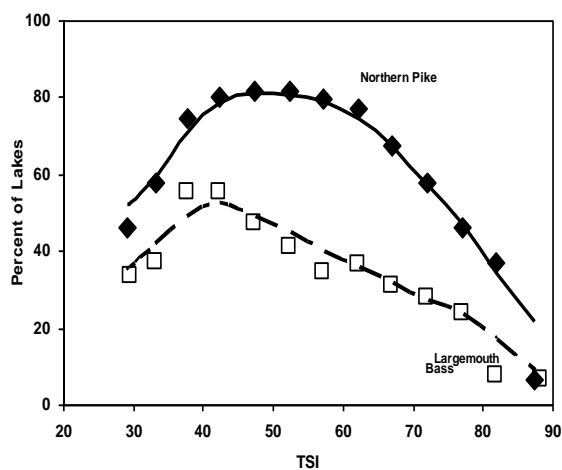
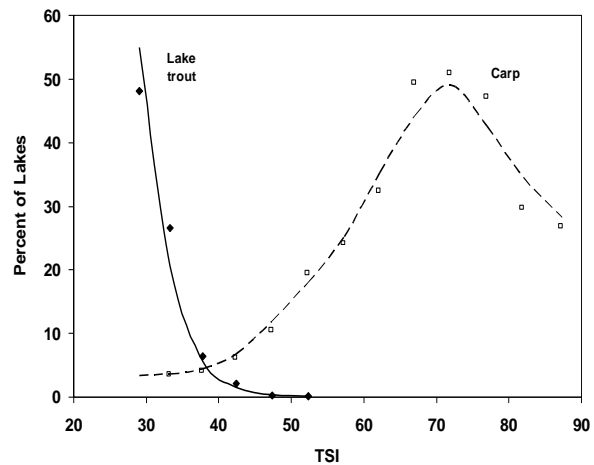
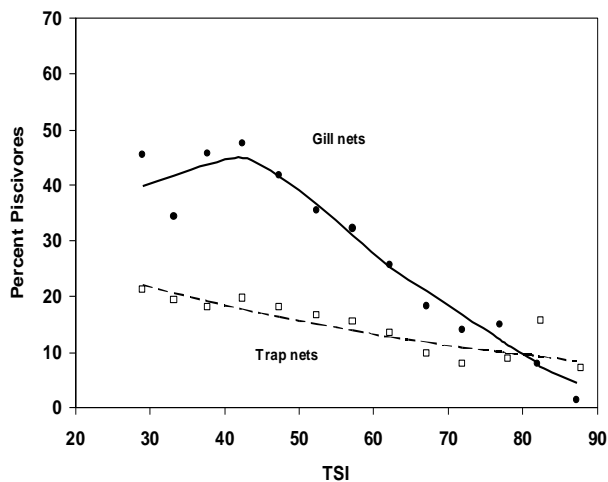
The relationships between piscivore species and lake TSI is depicted in Figure 1, which shows the number of species declining with TSI values greater than ~45. The relative abundance of northern pike and largemouth bass show a similar decline with increasing TSI values. The opposite relationship, however, was observed with carp, where relative abundance peaks at TSI values greater than ~70. These patterns reinforce lake management techniques that will return Musky Bay's clear water state for propagation of game fisheries while eutrophication favors the less desirable carp.

Eutrophication related oxygen depletion, warrants further consideration for effects upon natural recruitment of muskellunge in Musky Bay. As cited by Pratt and Neuswanger (2006), the LCO genetic strain of muskellunge deposit their eggs on the lake bottom and are dependent available oxygen along the sediment-water interface for survival. Eutrophic conditions may severely limit oxygen availability at this critical life cycle stage. Hence, lake management efforts should focus upon reducing P concentrations and other measures to increase muskellunge spawning habitat oxygen supply.

Figure 1. Lake Trophic Status and Fisheries

From Heiskary and Wilson, 2008. Relative fish abundance as compared to Secchi transparency-based lake trophic status (TSI). Derived from an analysis of MDNR fisheries records for 3,029 lakes (Schupp 1992). Graphics adapted from Schupp and Wilson (1993) and Schupp unpublished data: a) fish abundance vs. TSI; b) number of fish species vs. TSI; c) percent piscivorous fish vs. TSI; d) percent of lakes with lake trout and percent of lakes with carp vs. TSI; e) percent of lakes with northern pike and percent of lakes with largemouth bass vs. TSI; f) percent of lakes with yellow perch and percent of lakes with walleye vs. TSI.





c

Non-native Species Infestation Watch:

Zebra Mussels, Night Crawlers and Viral Hemorrhagic Septicemia.

Examples of exotic infestations to aquatic and terrestrial habitats are provided to indicate the scope of potential future threats to the watershed and not to provide a detailed list of potential infestations. Relatively recent infestation of curly leaf pondweed has rapidly expanded over larger portions of at least three LCO bays. Hence, resource management should be dedicated for evaluation, planning and implementation of measures to prevent, monitor and manage future outbreaks.

Zebra mussels

Dreissena polymorpha, is a small freshwater mussel that was originally native to the lakes of southeast Russia but has been spread through the Midwestern states including Wisconsin. Zebra mussels are very prolific and can spread quickly within a lake once introduced covering boats, docks and other substrates. Experts believe this invader has the potential to cause more economic damage than the Mediterranean fruit fly (Wisconsin Sea Grant, 2010) by affecting native species and influencing water quality.

Viral Hemorrhagic Septicemia, known as VHS, is a deadly infectious fish disease caused by the *Viral hemorrhagic septicemia virus* (VHSV, or VHSV). It afflicts over 50 species of freshwater and marine fish and is an **invasive infection** that has been associated with European fish farms. Viral Hemorrhagic Septicemia (VHS) is a deadly fish virus and an invasive species that is threatening Wisconsin's fish. VHS was diagnosed for the first time ever in the Great Lakes as the cause of large fish kills in lakes Huron, St. Clair, Erie, Ontario, and the St. Lawrence River in 2005 and 2006. Thousands of muskies, walleye, lake whitefish, freshwater drum, yellow perch, gizzard shad, redhorse and round gobies died. Many Chinook salmon, white bass, emerald shiners, smallmouth bass, bluegill, black crappie, burbot, and northern pike were diseased but did not die in large numbers.”

–Infected fish shed the virus in their urine and reproductive fluids. The virus can survive in water for at least 14 days. Virus particles in the water infect gill tissue first, and then move to the internal organs and the blood vessels. The blood vessels become weak, causing hemorrhages in the internal organs, muscle and skin. Fish can also be infected when they eat an infected fish. Fish that survive the infection will develop antibodies to the virus. Antibodies will protect the fish against new VHS virus infections for some time. However, the concentration of antibodies in the fish will drop over time and the fish may start shedding virus again. This may create a cycle of fish kills that occurs on a regular basis.”

–The virus grows best in fish when water temperatures are 37-54°F. Most infected fish will die when water temperatures are 37- 41°F, and rarely die above 59 °F. Stress is an important factor in VHS outbreaks. Stress suppresses the immune system, causing infected fish to become diseased. Stressors include spawning hormones, poor water quality, lack of food, or excessive handling of fish.” From the WDNR website
<http://dnr.wi.gov/fish/vhs/vhsfacts.html>

Forest Invasive: European Night Crawler

Invasions of the European earthworms, particularly the nightcrawler *Lumbricus terrestris*, have been noted to dramatically alter deciduous forests, by eating the duff, thus changing the type of seedbed, and the species of plants that can germinate there in the future. This species of night crawler, lives in vertical burrows, and eats fresh forest leaf litter. They can prevent the forest floor from being reestablished by eating all of the litter that falls each year. Hence the forest duff can be rapidly consumed, increase soil bulk density and induce drying. This can be expected to generate additional loss of nutrients, sediments and water volumes. In short, earthworm can alter deciduous forest - part of the declining forest syndrome and is the subject of intense research (Frelich, 2010).

Lake and Watershed Characteristics

Lac Courte Oreilles Morphometric Characteristics (area, depth and orientation)

Lake bay surface areas were determined using a Los Angeles Scientific Instrument Company (Lasico) model series 20 polar planimeter based on the WDNR's Lac Courte Oreilles published lake map with a water datum of 1286.51 (WDNR, 1972). Individual lake depth contour areas were determined by bay subtracting island/shoal areas. Volumes were calculated by spreadsheet for each bay strata using frustum of a circular cone: $V = 1/3 * H(A1 + A2 + \text{SQRT}(A1 * A2))$. Lake volumes were determined by contour area and summed

for each bay. Island/shoal volumes were also determined and subtracted by bay and contour sequence. Lac Courte Oreilles lake areas totaled 5030 acres or 0.2% less than previously determined 5039.8 acres noted by the WDNR. Total estimated volume was 168,739 acre feet versus the WDNR published value of 168,840 or a difference of 0.06%. Bay surface areas, volumes and fetch lengths used in lake modeling are summarized in Table 1 below.

Table 1. LCO Lake Morphometry

Basin	Area	Volume acre feet	Mean Depth Z feet	Area km2	Vol Hm3	Z m	Fetch mi	Fetch Km	Direction
Musky	270.7	1488	5.5	1.12	1.8	1.7	1.04	1.68	EW
Stuckey	96.6	1400	14.5	0.40	1.7	4.4	0.57	0.91	NS
West	1039.0	36134	34.8	4.31	44.6	10.6	1.70	2.74	NS
Central	1757.5	53862	30.6	7.29	66.4	9.3	2.75	4.42	NS
East	1763.4	74410	42.2	7.32	91.8	12.9	3.69	5.95	EW
NE Bay	102.4	1445	14.1	0.43	1.8	4.3	0.52	0.84	NS
LLCO	240	3672	15.3	1.0	4.5	4.7	0.76	1.2	EW

m = meters; Hm3 = million cubic meters, ft = feet. Zm=mean depth.

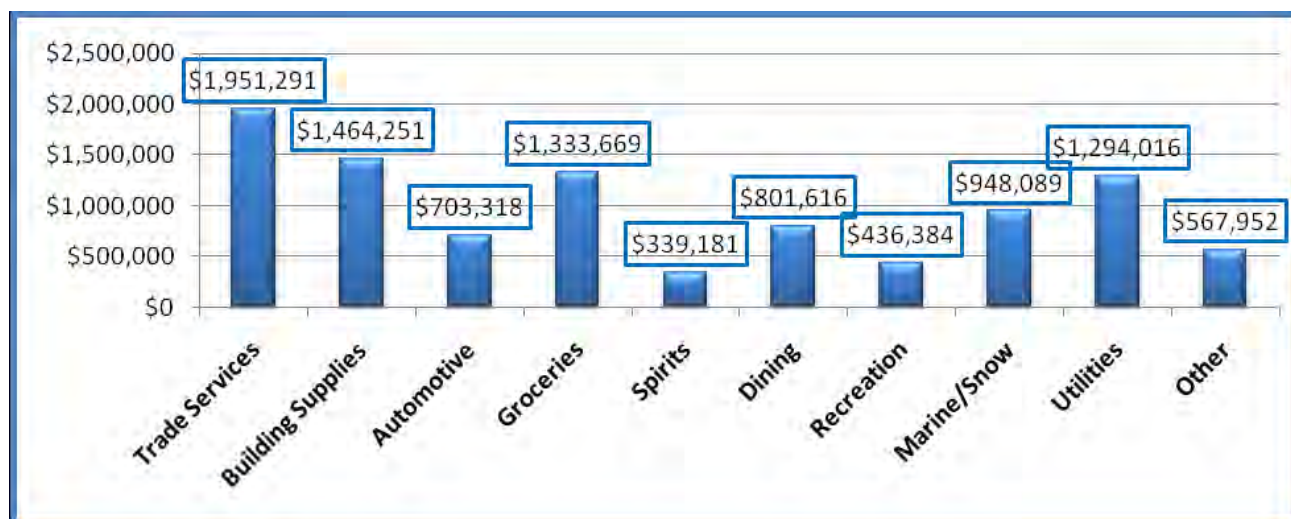
Cranberry Operation Discharges

Using the above bay volumes, an analysis of the relative magnitudes of a range of cranberry discharges by LCO bay was generalized based on the approximate surface area of cranberry production acres and the number of one-foot flooding and discharge events (1-5) per discharge location. For this purpose, the following cranberry operation acres were utilized: (1) 79 acres for the Musky Bay; (2) 97 acres for Stuckey Bay; and (3) approximately 7.5 acres for the east bay. Over the range of flooding events, cranberry discharges account for a percentage of bay volumes ranging from ~5-25% for Musky and Stuckey Bays and a much lower percentage of the total volume for the east bay (e.g. 0.01% - 0.05%).

Lac Courte Oreilles Economic Survey and Assessment.

Lac Courte Oreilles (LCO) is a popular and regionally recognized Hayward Area destination receiving an estimated 84,000 visitor days per year from full-time LCO residents + seasonal LCO residents (second home property owners) + their LCO guests - estimated from mail-in surveys sent to 650 LCO residents. LCO Residents and their guests purchase a wide variety of goods and services with estimated LCO resident annual expenditures, varying from about \$2 million dollars for trade services (plumbing, electricians, carpenters etc), \$1.5 million for building supplies, \$1.3 million for groceries and utilities, \$948 thousand dollars for marine/snowmobile, \$801 thousand for 2 November 28, 2010 LCO Economic Survey and Assessment dining out, and \$703 thousand for automotive. Survey responses were summed by category from the 219 respondents and then extrapolated to 650 LCO residents. In total, estimated LCO resident total 2009 expenditures were ~\$9.8 million. Using a range of multipliers, the total effects of these expenditures in the LCO region was approximated to be about \$ 10.8 million to \$14.8 million annually. These values represent about 9% of total Sawyer County travel and tourism revenue noted in 2008. Travel and tourism, referred to as one of the three pillars of Wisconsin industry along with agriculture and manufacturing, was estimated by the Wisconsin Department of Tourism to be about \$12 billion in 2009 and responsible for about 300,000 jobs (Davidson-Peterson Associates, 2010).

Figure 2. From Lac Courte Oreilles Economic Survey and Assessment, Wilson (2010).



Residential Development

Recreational real-estate development is a major trend for northwestern Wisconsin with LCO lakeshore and secondary new home development expanding from the 1960's to present from about 206 to over 650 residences. The number of resorts has dropped markedly from 18 to 3 with the trend for resorts to sub-divide into private, single family residences. Present LCO shoreland zoning, "category 1" (least restrictive) classification, requires new residential developments to have a minimum lot width of 100 feet and a minimum structure setback of 75 feet. New development (post 1998) requires a 35-foot shoreline buffer zone. COLA has actively promoted shoreland buffer restoration or protection for all properties. Much remains to be done to establish shoreland buffers around the lake.

Sawyer County's Comprehensive Plan (Northwest Regional Development Commission, 2010) indicates urban growth rate projections of about 27 percent by the year 2035, with occupied housing units projected to increase by 46.5 percent. "Sawyer County is projected to grow the second most between 2000 and 2035 compared to the other nine counties in the northwest region. LCO is located in Bass Lake and Sand Lake Townships." By the year 2030, Bass Lake is projected to grow about 34% in population and about 55% in the number of households (about 297 additional households) while Sand Lake has a slightly lower growth projection rate of 13% with a 30% increase (about 50 additional households).

Sawyer County Ordinances

Sawyer County has updated their ordinances for shoreland buffer areas and development with Classification 1 covering LCO with many excellent provisions including a cap on impervious surfaces. It is proposed that Sawyer County consider adoption of additional new development rules to better address new development stormwater volume control practices. For example, the first 1.25 inches of runoff from impervious areas would be treated to the greatest extent practicable using infiltration, reuse, and filtration practices. This would remove about 90%+ of the phosphorus and sediment loads from the site depending upon the site disturbance areas that trigger ordinance provisions. It is suggested that COLA work with Sawyer County to review potential upgrades to the County Codes to include new development volume control standards.

Table 2. Residential shoreline development on Lac Courte Oreilles (from Pratt and Neuswanger, 2006).

Year	Residences	Resorts
1967	206	18
1998	542	3
2005	651	3

Lac Courte Oreilles Watershed Characteristics

The watershed areas and characteristics were summarized from the WDNR interactive Geographic Information System website (www.dnr.wisconsin.gov) using the Surface Map function linked to the Department of Agricultural & Biological Engineering, Purdue University Watershed Delineation Program (Engel, 2010). Summary land uses, soils and other information were extracted and summarized below. In total, the watershed covers a surface area of 68,990 acres to the LCO outlet with the majority of land cover in forest 36,517 acres (53%) and water covering about 21,557 acres (31%).

Grass and pasture were tabulated to cover over 5,300 acres with High Density and Low Density residential covering about 2,900 acres and agriculture about 2,704 acres (Table 3). Forest plus water categories cover about 84% of the watershed with agriculture, commercial, industrial and residential less than 9%. The coverage of agricultural fields and grass lands can be observed on the west sides of Round Lake and LCO.

Figure 3. Google Map Watershed Overview with the City of Hayward in upper left quadrant.



Table 3. Summary land uses in the Lac Courte Oreilles Watershed.

LCO Land Uses	Acres	Percent
Forest	36,517	52.9%
Water	21,557	31.2%
Grass/Pasture	5,307	7.7%
Agriculture	2,704	3.9%
Low Density Residential	2,099	3.0%
High Density Residential	751	1.1%
Commercial	52	0.1%
Industrial	4	0.0%
Total (acres)	68,990	

Figure 4. Highlighted View of LCO Watershed.



Land areas draining into Lac Courte Oreilles cover a total of about 68,990 acres with the largest tributary areas Osprey Creek (from Round and Osprey Lakes) with about 18,661 acres, Whitefish Creek (drainage from Sand and Whitefish Lakes) covering about 17,855 acres, Grindstone Creek covering about 14,656 acres, Spring Creek covering 4,799 acres

and West LCO Watershed covering about 3,179 acres. Direct drainage and miscellaneous areas accounted for about 4,000 acres (see Tables 3 and 4).

Table 4. LCO Subwatersheds

Subwatershed	Acres	%
Osprey Creek	18,661	27.0%
Whitefish Creek	17,855	25.9%
Grindstone Ck	14,656	21.2%
Ghost Creek	4,799	7.0%
Direct Drainage	3,987	5.8%
West LCO	3,179	4.6%
Ring Creek	281	0.4%
Unnamed Creek	234	0.3%
Total acres to LCO Outlet	68,990	
Little LCO	1,487	2.1%

Watershed Soils

The U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS) has grouped soils into categories (A, B, C, D) based on their hydrologic characteristics and runoff potential under similar storm and vegetation conditions. The four hydrologic soil groups are defined below:

Hydrologic Soil Group A (Low runoff potential): The soils have a high infiltration rate even when thoroughly wetted. They chiefly consist of deep, well drained to excessively drained sands or gravels.

Hydrologic Soil Group B: The soils have a moderate infiltration rate when thoroughly wetted. They mainly are moderately deep to deep, moderately well drained to well drained soils that have moderately fine to moderately coarse textures.

Hydrologic Soil Group C: The soils have a slow infiltration rate when thoroughly wetted. They chiefly have a layer that impedes downward movement of water or have moderately fine to fine texture.

Hydrologic Soil Group D (High runoff potential): The soils have a very slow infiltration rate when thoroughly wetted. They chiefly consist of clay soils that have high swelling potential, soils that have a permanent high water table, soils that have a clay layer at or near the surface, and shallow soils over bedrock.

Hydraulic conductivity rates vary greatly by soil type and texture varying from sands infiltrating at rates of 10 + inches/hour, loams less than 0.8 inches per hour and clays usually infiltrating less than 0.3 inches per hour. Incorporating infiltration characteristic will be important for future watershed development using Low Impact Development (LID) techniques that treat runoff on site for typical storms (up to the one year 24 hour storm) as well as on-site sewage treatment systems (septic tanks).

Hydrologic Soil Group soils A and B cover about 64% of the watershed with less infiltrating C and D soils common in about 1/3 of the watershed (Figure 3). There is a higher prevalence

of D and C soils groups in Spring, Osprey, Grindstone and Whitefish drainage areas that result in higher runoff values (Table 5). New development and road projects with impervious surfaces (roofs, driveways, roads) will also tend to generate greater runoff from A and B soils would have otherwise infiltrated. Hence, future development should consider preserving A and B soils for infiltration as is possible. Runoff from D soils is high such that adding impervious surfaces does not greatly increase runoff by comparison with A soils. A and B soils were much more prevalent in the Ring and West drainage areas (e.g. ~90%) and likely translate into greater infiltration of runoff volumes. New developments should observe minimal soil disturbance practices during construction and apply better site designs that preserve forest and stream buffer areas as much as possible.

Figure 5. Prevalence of HSG Soil Types in LCO Watershed.

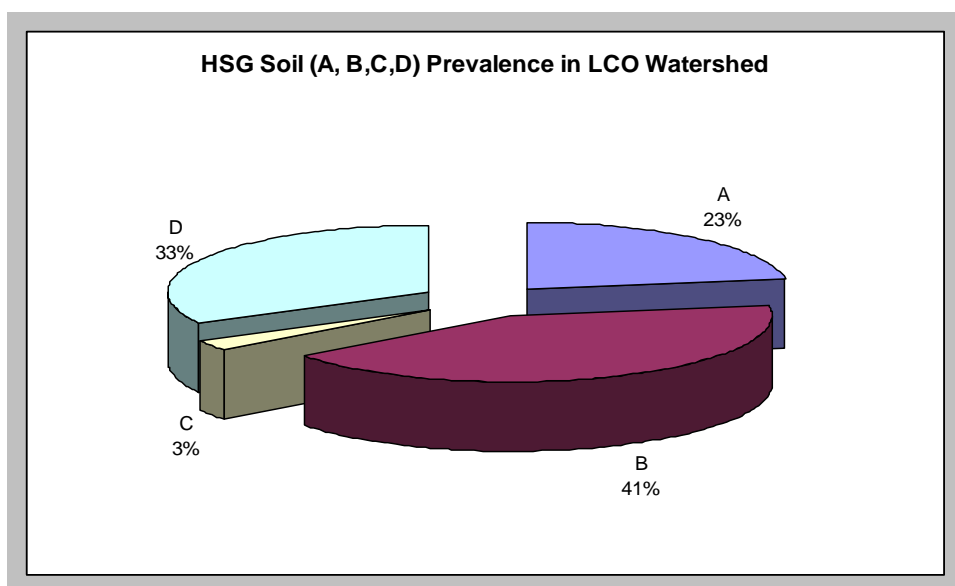


Table 5. Hydrologic Soil Group Occurrence by LCO drainage area.

	Ghost Creek	Osprey Creek	Grindstone Creek	Whitefish Creek	Ring Creek	West	LLCO
D soils %	23.6%	25.8%	34.8%	32.7%	16.0%	10.6%	1.1%
C soils %	0%	0%	0%	5%	0%	0%	16.4%
B soils %	7%	53%	22%	45%	76%	80%	82.6%
A soils %	70%	21%	43%	17%	8%	10%	

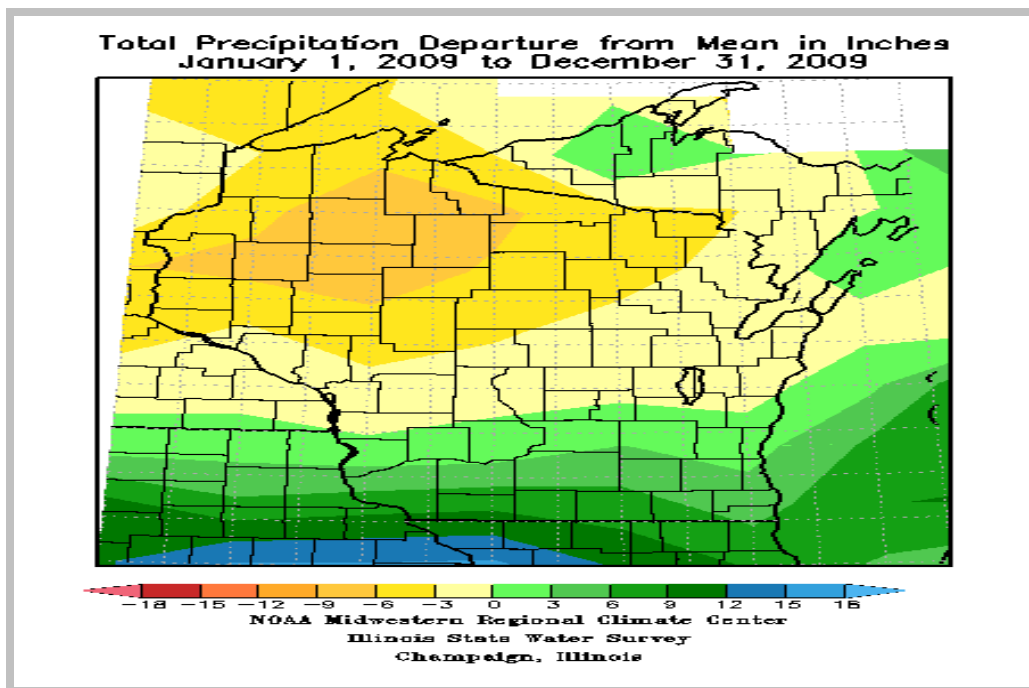
Hydrologic Budget: Climatological Summary. Precipitation

The long-term precipitation average (1971-2000) for Couderay, WI used for water budget purposes was 34.5 inches with most (63%) of the rainfall occurring during the growing

season of May through September (Table 6). Winter snow fall has typically been about 55 inches with considerable variability as regional values have varied from about 46 inches to 76 inches. Calendar year 2009 was a dry year in Wisconsin, centering on Sawyer County with about 6-9 inches below normal rainfall (Figure 6).

The intensity of rainfall events can have a significant effect on the nature of runoff to streams and lakes. Hence, data for northern Wisconsin was summarized in Table 7 shows that most rainfall days with events exceeding 0.01 inch/day are on the order of 90 per year, with 74 event days exceeding 0.1 inch/day, 24 event days exceeding 0.5 inch/day and about 9 event days exceeding 1.0 inch/day (Table 7). Until the new Atlas 14 is completed for Wisconsin, rainfall frequency data from the old TP-40 will serve as temporary benchmarks and are plotted in Figure 7. Storm frequency range from 1 Year ~ 2.3 inches, 2 Year ~2.75 inches, 3 Year ~ 3.2 inches, 10 Year ~ 4 inches, 50 Year ~ 5 inches and the 100 year storm ~ 5.5 inches.

Figure 6. 2009 Wisconsin Precipitation Patterns.



**Table 6 . Precipitation Summary Station: 471847 COUDERAY 7 W, WI
1971 - 2000 NCDC Normals**

Element	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
Precip (in)	1.07	0.96	1.87	2.63	3.27	4.48	4.76	4.72	4.37	3.29	2.08	1.02	34.52

Figure 7. TP 40 Storm Frequency Data (Data being recalculated by National Oceanic and Atmospheric Administration (NOAA) under contract with the WDNR.)

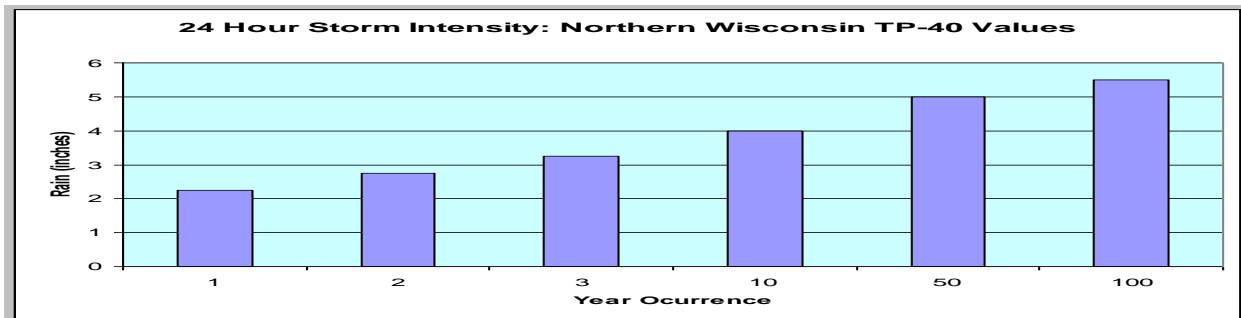


Table 7. Precipitation Climatology Derived from 1971-2000 Averages

Month	# Days Total ≥ 0.01"	# Days Total ≥ 0.10"	# Days Total ≥ 0.50"	# Days Total ≥ 1.00"
JAN	5.0	3.2	0.4	0.1
FEB	3.8	2.9	0.5	0.1
MAR	6.0	4.6	1.0	0.4
APR	7.8	6.8	1.7	0.5
MAY	8.8	7.3	2.5	0.7
JUN	10.1	8.8	3.4	0.9
JUL	8.9	7.9	3.2	1.5
AUG	9.4	8.0	3.4	1.5
SEP	9.2	8.1	2.7	1.1
OCT	7.4	6.5	2.0	1.0
NOV	6.0	4.9	1.3	0.5
DEC	4.7	3.4	0.5	0.0
Annual	88.6	74.1	23.5	8.6
Winter	13.5	9.6	1.4	0.2
Spring	22.7	18.8	5.2	1.5
Summer	28.4	24.6	10.0	3.9
Fall	22.5	19.5	6.0	2.6

Annual/seasonal totals may differ from the sum of the monthly totals due to rounding.

Recent weather assessments prepared for Iowa –Climate Change Impacts on Iowa 2010 (Iowa Climate Change Commission, 2011) include main findings that changes to its economy and human welfare are well underway. The report identifies changes to Iowa's climate,

agriculture, environment, public health, and infrastructure. The state's increased rainfall and humidity have allowed unwanted pests and pathogens to spread, leading to an increase in pesticides. Increased flooding in 2008 cost the state and federal government \$3.5 Billion in lost crops, displaced homes and damaged businesses. The report included a general graphic for the Wisconsin, Iowa and Minnesota area of the upper Midwest showing a 31% increase in heavy precipitation (top 1% of precipitation events).

The long-term rainfall record (1891 – 2009) for Northwest Wisconsin was plotted by NOAA and summarized in Figure 8. Recent dry and wet periods since 1990 are evident with three below normal dry years noted since 2000. The recent succession of dry years resulted in very dry conditions noted during the 2009 monitoring season with many dry wetlands and below normal lake levels noted in the LCO watershed. 2009 LCO lake levels were down about 6-9 inches from average summer conditions according (Pulford, personal comm.)

By comparison, the 2010 precipitation through October for the nearest regional weather center (Eau Claire) totaled 29.59 inches through early November, 2010 which is about 2.7 inches above normal. Daily precipitation at the US Geological Survey (USGS) Chippewa River site near Winter during 2010 was limited until mid-June when there were several >0.5 inch storms followed by another dry period extending into the severe storms of September (Figure 9) with ~two one-in-a-year events back to back.

Figure 8. Long-term annual precipitation record.

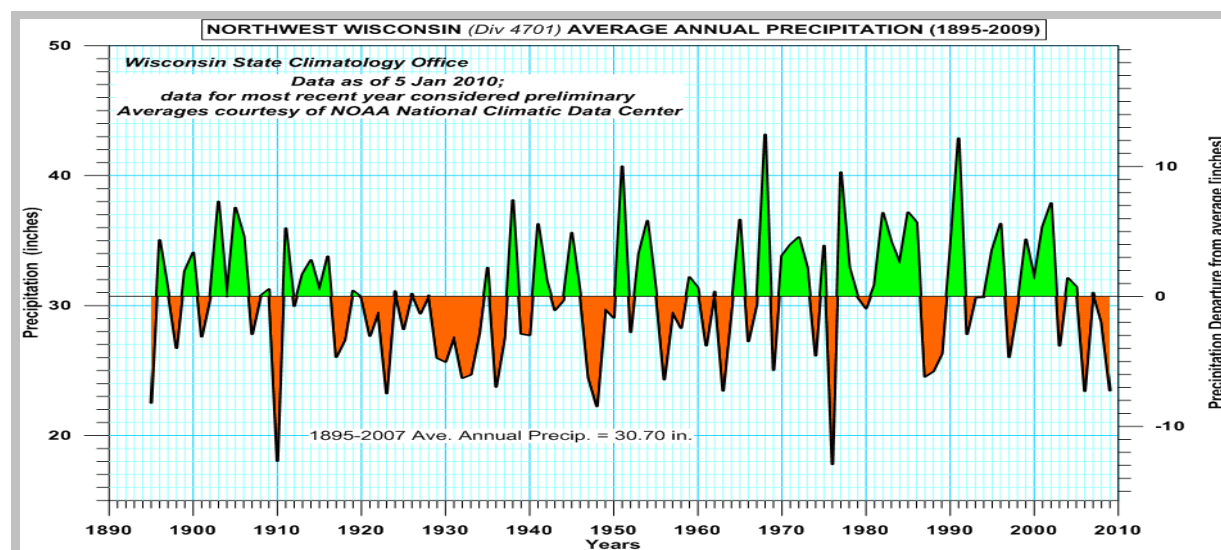


Figure 9. 2009-2010 Chippewa River near Winter Precipitation Plot.

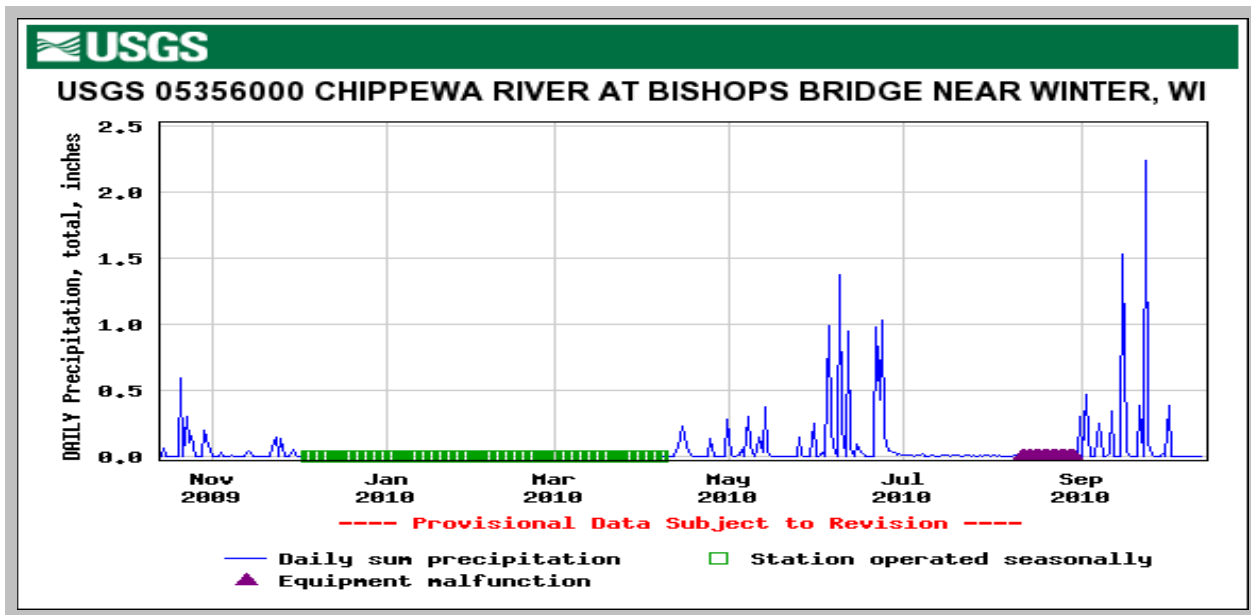
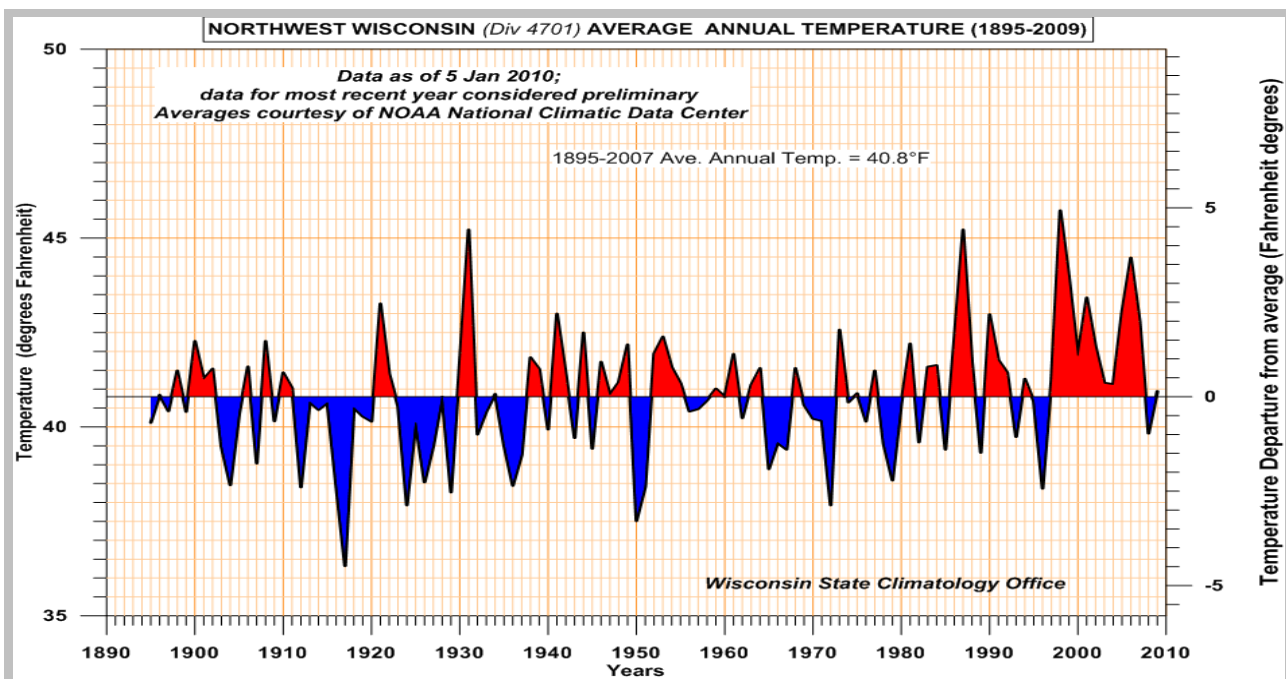


Figure 10. Long-term average annual temperatures for Northwest Wisconsin.



Temperatures

The annual mean long-term temperature for the Northwest Wisconsin NOAA region is 40.8 degrees F with recent years showing substantial increases from the long-term average (Figure 10). Typical averages are about 23 degrees F in the winter and 75 degrees in the summer with about 7 days with temperatures exceeding 90 DF. The LCO watershed is in an epicenter of summer and winter warming patterns noted from 1950-2006 with a peak

warming of 2-2.5°F across northwest Wisconsin (WICCI, 2009). Wisconsin is becoming "less cold", with the greatest warming during winter-spring and nighttime temperatures increasing more than daytime temperatures.

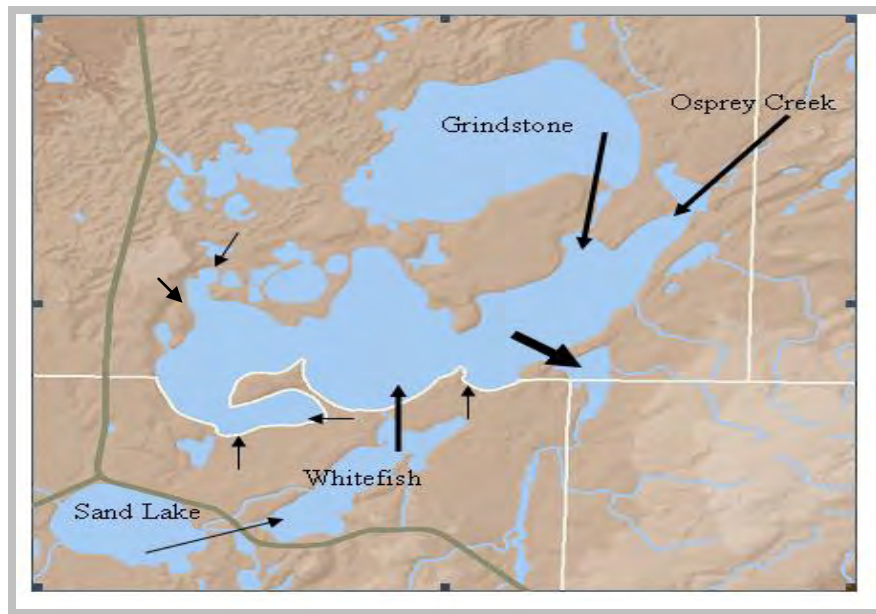
Evaporation

Evaporation rates plotted for Wisconsin by NOAA were estimated for the LCO region of Sawyer County to be about 30.5 inches per year. Of this, NOAA estimates approximately 7 inches of evaporation occurs over the November-April (ice season) or about 1.2 inches per month.

Surface Water Hydrology

The LCO watershed does not have continuous surface water gauging stations and in general, there are relatively few continuous flow gauging stations in Northwestern Wisconsin. Data from the nearest continuous gauges located on the Chippewa River at Winter, WI (790 square mile watershed) and at the Namekagon River at Leonards, WI (126 square mile watershed) were assessed using available data for both sites. The Chippewa River at Winter is downstream of the 15,300 acre Lake Chippewa and the dam operated by Xcel Energy. The Lac Courte Oreilles (LCO) Band of Chippewa operates an electrical power generation facility at the dam power generation and as such, the Chippewa River at Winter is subject to flow regulation. The Chippewa River at Winter is the nearest continuous flow gauging station to LCO with a data record from 1912 to present. The Namekagon River site at Leonards, WI with ~10 years of records (1996-2001 and 2005 to present) is cooperatively operated by the USGS and the National Park Service, St. Croix National Scenic Riverway. The drainage area for the Namekagon River at Leonard is comparable to that of the LCO (e.g. 126 square miles versus 108 square miles, respectively).

Figure 11. Lac Courte Oreilles Surface Flow Network



Available annual flows from 1970-2009 for the Namekagon River at Leonards, WI and the Chippewa River at Winter were normalized to flows for the LCO based on yearly flows prorated by area and plotted in Figure 12. Derived LCO flows estimated from Namekagon

River flows over a 10 year period of record, were slightly greater (about 7%) than those calculated from Chippewa River flows at Winter. While these values are approximations for the LCO system, they are the only available data. As such, the lack of gauged stations in the area and specifically for the LCO outlet are critical data gaps. The estimated flows give a useful range for comparison and overview modeling purposes and are the best available data.

Long-term USGS flow data for the Chippewa River at Winter, WI was obtained and reduced to average annual runoff plotted in Figure 13, for the 1970-2009 time period with 90th percentile, 50th percentile and 10th percentiles also noted. Recent years show a marked pattern of lower than normal runoff with a long-term downward trend line for 1970 to 2010 (linear regression line superimposed), with ~ 3 + inches decline over 39 years or a decline of 0.08 inches runoff per year. Flows for 2005 -2009 hover around the 10th percentile with 2009 values at the 3rd percentile (or about 5.9 inches of runoff per year). Chippewa River flows (at Winter) remained at very low flow until the 2010 mid-summer storms (e.g. July, 2010) that began the recharge of wetlands and stream flows (Figure 14).

Figure 12. Estimated LCO Outlet Annual Volumes (cfs) 1970-2009 based on Chippewa River near Winter and Namekagon River at Leonard flows.

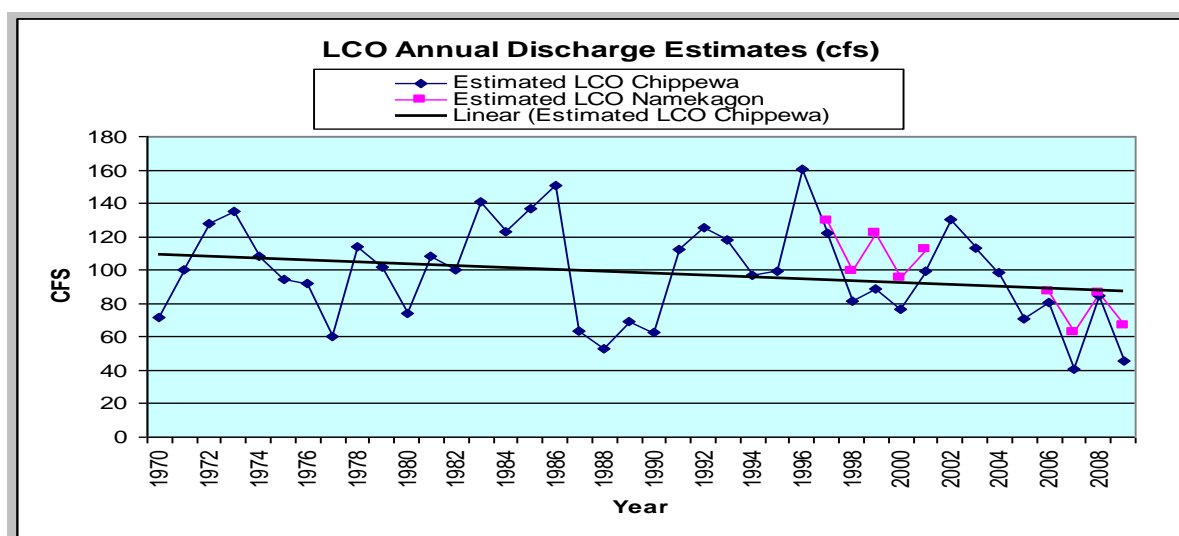


Table 8. Chippewa River (near Winter) statistical summary of annual flows (1970-2009) expressed in cubic feet per second (cfs) and inches per year of runoff.

Percentile	Annual Mean CFS	Runoff Inches
90 %	991	17.0
75%	883	15.2
50%	728	12.5
25%	557	9.6
10%	456	7.8
3%	341	5.9

Figure 13. Long-term Flows. USGS gauging station: Chippewa River at Winter (inches of runoff per year).

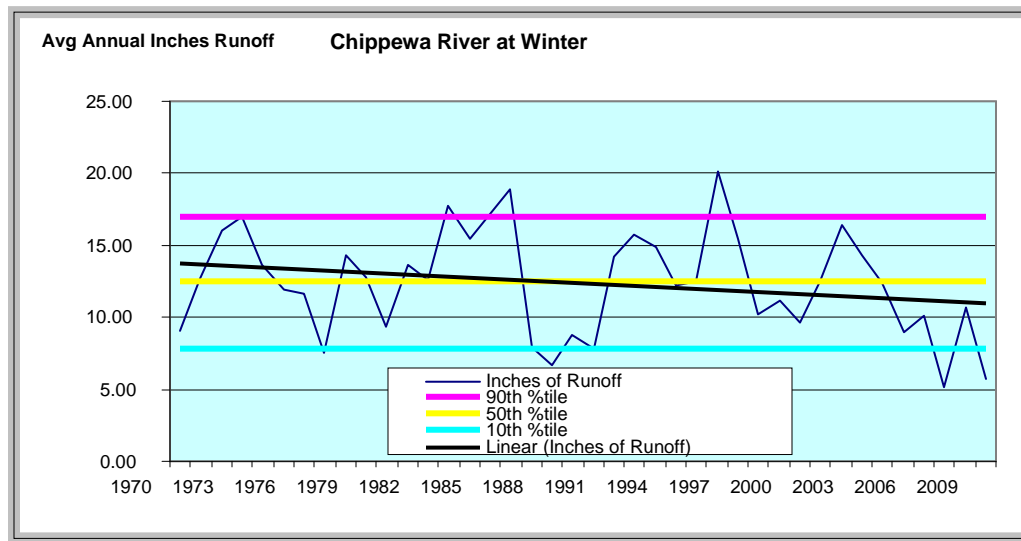
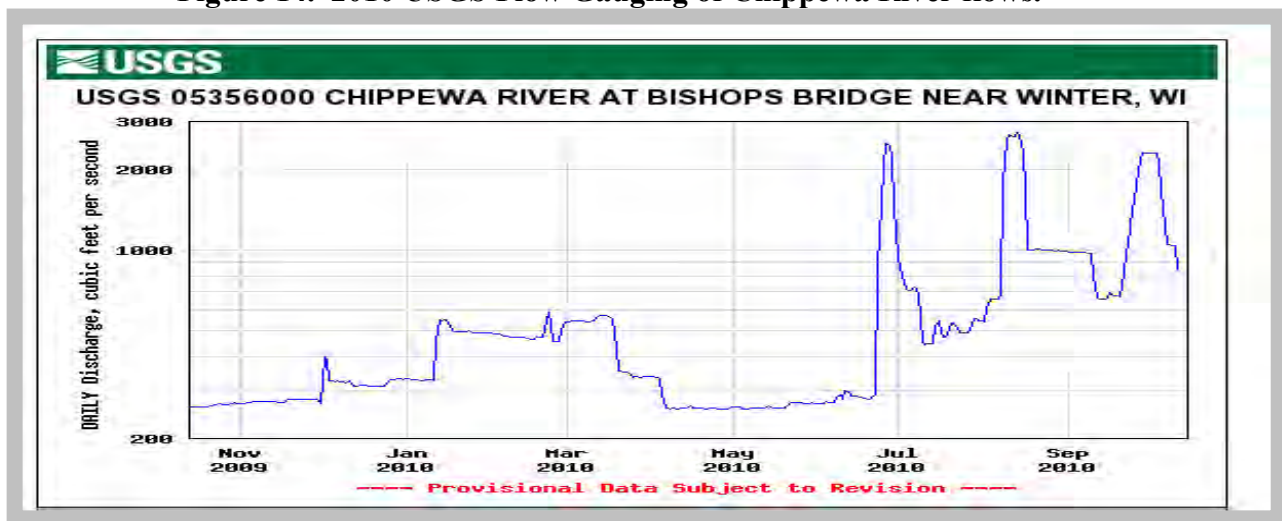


Figure 14. 2010 USGS Flow Gauging of Chippewa River flows.



LCO Outlet Volumes

LCO outlet volumes were estimated from Chippewa River flows at Winter, WI based on prorating of water yields. Annual flows were estimated to range from high flow years (90th percentile) of 137 cfs (122.7 Hm³ or million cubic meters), to average flows (50th percentile) of 101 cfs (or 90.2 Hm³) to 47 cfs (or 42.3 Hm³) for 2009 in Table 9. The highest projected flows through the system were likely realized in WY1996 with an annual average flow of ~160 cfs. Estimated annual runoff variability over the past decade was substantial and varied by a factor of ~ 3 from the very dry years such as 2009 to the wet years similar to 1996 and 2002.

Over the 1970 to 2009 time period, there has been observed a general decline of average annual flows of about 20 cfs or about 18%. Reduced flows have been more pronounced

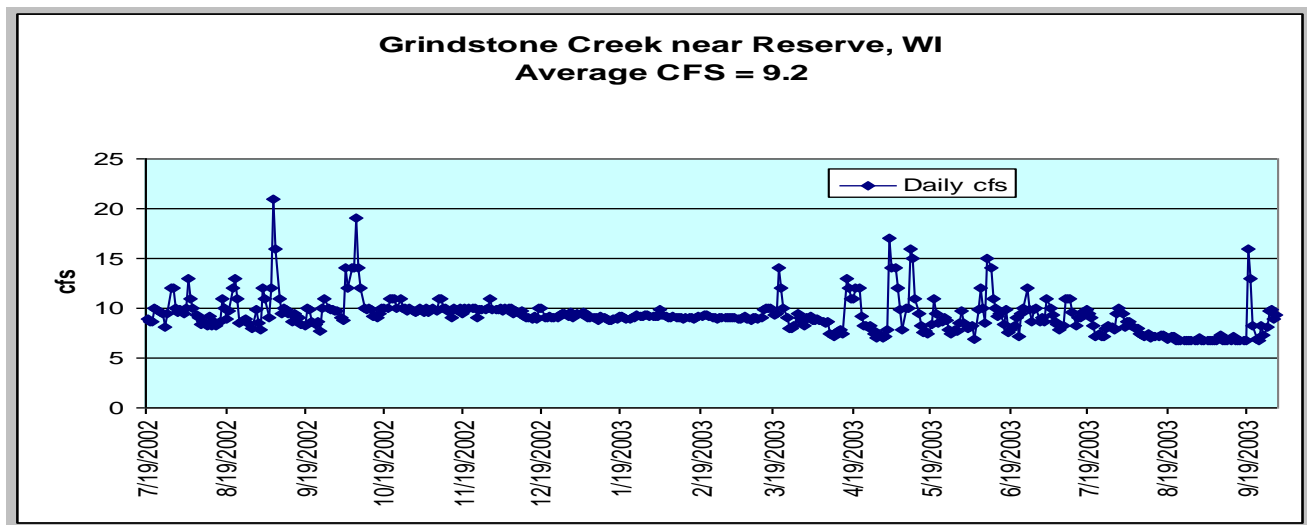
from 2005 to 2009 resulting in lower annual water and phosphorus loads to LCO. Lower flows and phosphorus loading to LCO will influence in-lake responses (e.g. increased transparencies and reduced phosphorus and chlorophyll-a concentrations). The return of wet years produce greater phosphorus loads, chlorophyll-a concentrations and somewhat reduced transparencies.

Previous studies of LCO included “Lac Courte Oreilles Management Plan. Phase I: Water Quality Study of Lac Courte Oreilles; Phase II: Hydrologic and Phosphorus Budgets” (Barr, 1998) was accomplished during the highest flows estimated for the LCO system during the past 40 years (e.g. about 160 cfs at the LCO Outlet) and since then, flows through the system have been declining.

Table 9. Estimated annual average flows in cubic feet per second and million cubic meters (Hm3) at LCO outlet

Percentile Flow	CFS	Hm3
90 %	137	122.7
75%	121	108.4
50%	101	90.2
25%	77	69.0
10%	63	56.5
3%	47	42.3

Figure 15. Grindstone Creek near Reserve, WI continuous flows (2002 – 2003).



In the relatively wet water year (October 1 to September 30) WY 2002, the USGS monitored Grindstone Creek which was found to contribute 9.2 cfs annual average flow to LCO system. This represented about 7% of the total LCO outlet volume from the Grindstone Creek’s 4 square mile watershed. This translates into about 1.3 cfs per square mile which was quite similar to the 1.2 cfs per square mile noted for the Chippewa River near Winter, WI for the same period. Grindstone Creek, with substantial D (clay) soil coverage, exhibits relatively

flashy (rapid increases and decreases) runoff responses contrasted by relatively stable flow periods over the winter (base flows from groundwater contributions (Figure 15).

Figure 16. Estimated Long-Term LCO Outlet Volumes (Average cubic feet per second (CFS) per year).

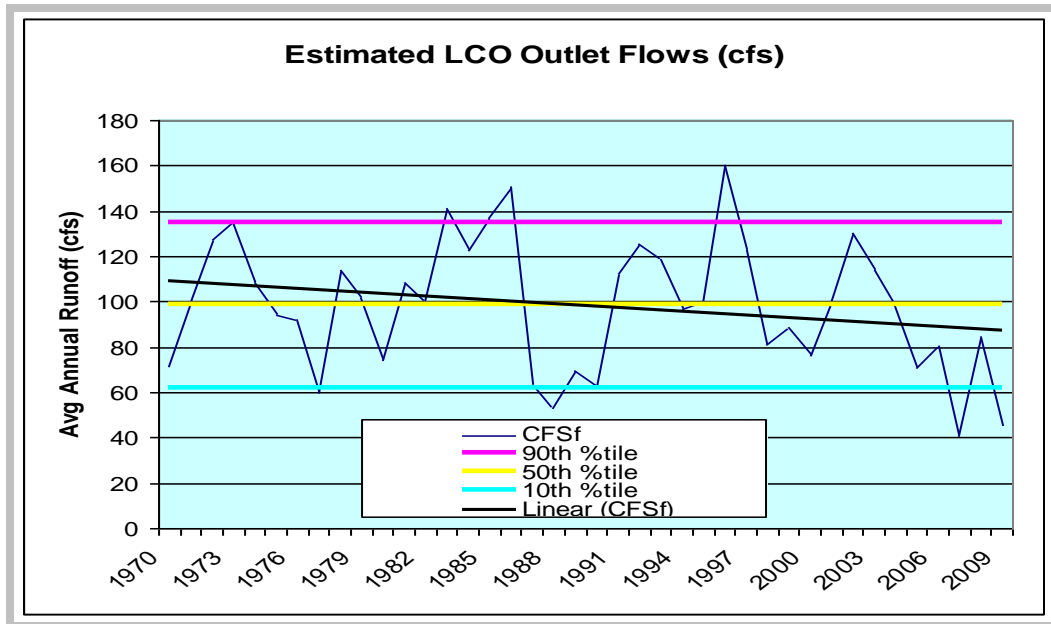


Table 10. Estimated LCO Flows by Subwatershed.

Subwatershed	Estimated Lac Courte Oreilles Flows by Drainage Area					
	2009 cfs	10th cfs	25th cfs	50th cfs	75th cfs	90th cfs
Osprey Creek	12.6	16.8	20.6	26.9	32.3	36.6
Whitefish Creek	12.1	16.1	19.7	25.7	30.9	35.0
Grindstone Creek	9.9	13.2	16.1	21.1	25.4	28.7
Spring Creek	3.2	4.3	5.3	6.9	8.3	9.4
Direct Drainage	2.7	3.6	4.4	5.7	6.9	7.8
West LCO	2.1	2.9	3.5	4.6	5.5	6.2
Ring Creek	0.2	0.3	0.3	0.4	0.5	0.6
Unnamed Creek	0.2	0.2	0.3	0.3	0.4	0.5
Total acres	46.6	62.2	76.0	99.4	119.4	135.2

Flows for estimation of water balances within the LCO flow network were developed from average runoff values for the entire system prorated by drainage areas as defined in Table 10, above. Estimated annual average outlet volumes for the LCO system are depicted in Figure 16, with percentile levels superimposed (10th percentile flows = low flows).

Lake Data Analysis

Lake Mixis The vertical mixing of lake water layers due to wind is related to the intensity of summer thermal stratification, duration of storms, length of fetch & orientation to

predominant winds, shoreline height/protection, mean and maximum depths and other factors. As storm intensities increase coupled with lengthening of growing seasons and warmer temperatures related to a variable climate, the mixing status will be an important factor in future lake conditions relating to sedimentation, internal loading of phosphorus and oxygen dynamics.

Heiskary and Wilson (1995) summarized previous studies and have related mixing status to average lake total phosphorus, chlorophyll-a and related Secchi transparency. In their effort, they defined three classes of lake mixis: polymictic (shallow lakes that frequently mix top to bottom), intermictic (somewhat deeper lakes that mix occasionally mix top to bottom) and dimictic lakes (maximum depths greater than 35 feet that mix top to bottom in the spring and fall). In general, their analysis suggested that (1) most dimictic lakes tended to have maximum depths greater than 10 m (33 feet), and surface area: maximum depth ratios less than 20:1; and (2) polymictic lakes had maximum depths less than 8 m (~26 feet) and surface area: maximum depth ratios greater than 30:1. Whitefish Lake, noted to have a classic dimictic thermal pattern with the coldest bottom waters, has a maximum depth of 105 feet and a surface area: maximum depth ratio of 11. All of the deeper LCO bays had surface area : maximum depth ratios exceeding 20:1.

Using their classification and monitored temperature – dissolved oxygen profiles, lake mixis types were assigned to each of the primary lakes and bays within the LCO watershed (Table 11). The shallower areas (Musky Bay, Stuckey Bay, and Northeast Bay) were classified as polymictic while the deep main bays (West, Central and East) were classified as weak dimictic meaning that these bays showed evidence of mixing over the course of the growing season. Intermictic mixing patterns were identified in Sand Lake – meaning the lake mixes occasionally from top to bottom in response to storm events. The weakly dimictic bays, based on measurements of 2000, 2002, 2007 and 2009, periodically exhibited weak clinograde temperature and dissolved oxygen patterns with bottom waters frequently warming to 50 to 55 degrees F (from 32 degrees F in the spring).

In contrast, the deep Whitefish Lake (max depth of 105 feet) had the coldest hypolimnetic water (~ 40 degrees F on July 18, 2007) and the most defined thermocline – e.g. most distinct decline of temperature with depth and a well defined hypolimnion. All of the dimictic bays and lakes tended to exhibit oxygen concentrations less than 5.0 mg/L (the oxygen concentration crucial for sports fisheries maintenance) below 9-11 m (or greater than 30 to 36 feet) during peak growing season conditions. This data indicates a relatively high volumetric oxygen depletion rates in these lakes such that the bottom waters have less than 5 mg/L within 60 to 90 days from the onset of spring thermal stratification. Example temperature and dissolved oxygen profile graphs are included in Appendix C.

Table 11. Lake Mixing Patterns (strong thermal, weak and well-mixed).

Lake / Bay	Max	Mean	Surface Area to Max Depth	Mixis Type	Depth
	Depth feet	Depth feet	(ha/m)	P, I, D	DO < 5

LCO Musky Deep	16	6	22	Polymictic	~2m peak
Stuckey	24	15	5	Polymictic	
West	67	35	21	Dimictic - weak	~10 m
Central	63	31	38	Dimictic - weak	~10m
East Deep	92	42	26	Dimictic - weak	~10m
NE Bay	25	14	5	Polymictic	
Little LCO	46	15.3	21		
Grindstone	60	30*	78	Dimictic - weak	~11m
Sand	50	21*	28	Intermictic	~7m
Whitefish	105	45*	11	Dimictic	~11m

* From Barr, 1998

In 1999, the USGS collected sediment cores in Musky Bay, Stuckey Bay, LCO central and LCO northeast bay to examine historical water quality patterns (Fitzgerald et al, 2003). All of the sites sediments were described as dark organic-rich muck or black muck indicating enriched sediments from oxic and anoxic littoral and profundal zones. Iron and phosphorus at the Musky Bay site were further examined. Sediment characteristics since ~1980 indicate two very distinct patterns: (1) sediment phosphorus content has increased exponentially while (2) iron values have declined in nearly dramatic fashion (Figures 17a, 17b). The report noted that “a rotten egg” odor was detected throughout the entire core, implying sulfate reduction as a major organic matter decomposition pathway. With sulfide in excess, all iron would precipitate as monosulfides and pyrite” thereby stripping iron from the sediments. Accordingly, since ~1980 the iron to phosphorus molar ratios were noted to decline from ~7: 1 to ~ 1 : 1 as the iron has been removed by pyrite reactions leaving very low values for combining with phosphorus compounds in oxygenated conditions. Concentration ratios less than ~3:1 indicate lower control by iron of labile sediment P and thus a greater likelihood of internal P release. Sulfur data may also warrant further review for methyl mercury considerations.

Figure 17 a. Musky bay total phosphorus content (%) by depth/age dating ; 17 b. Iron content (%) by sediment depth/age. (From Fitzpatrick et al, 2003, data provided by Paul Garrison).

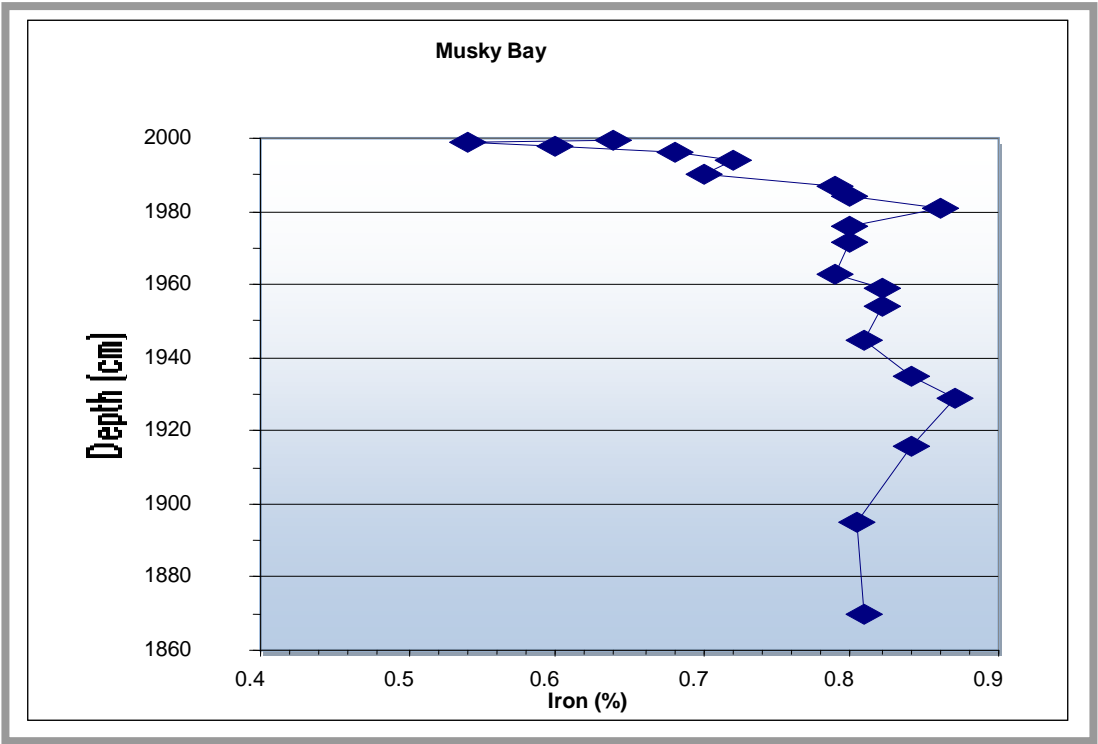
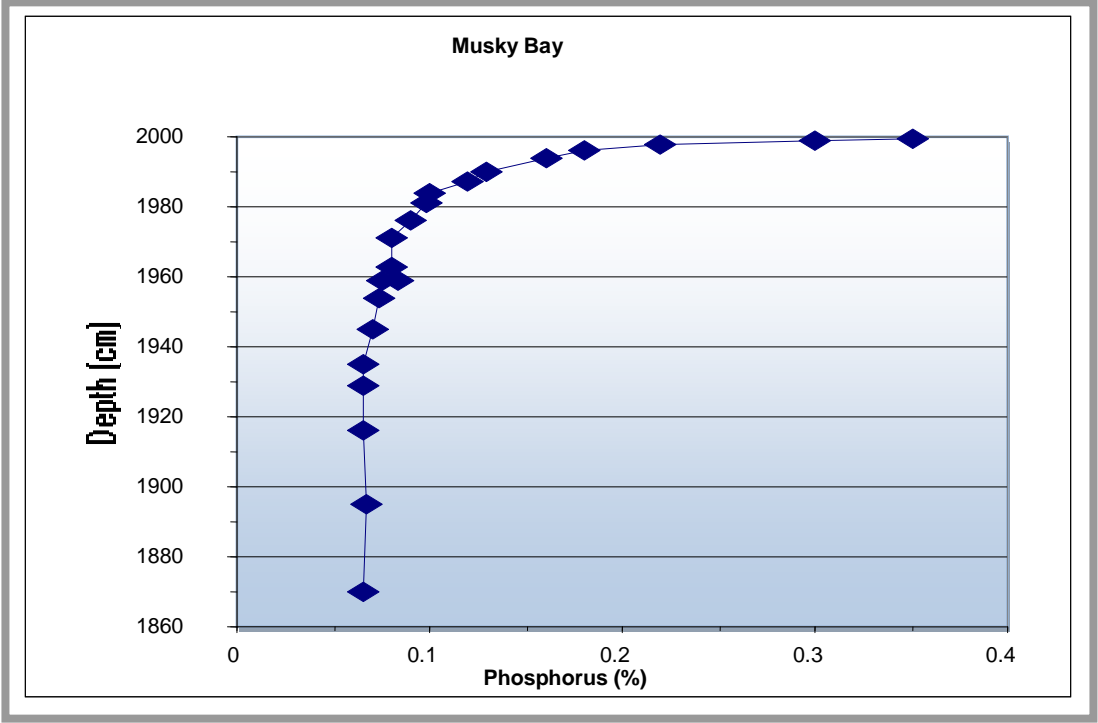
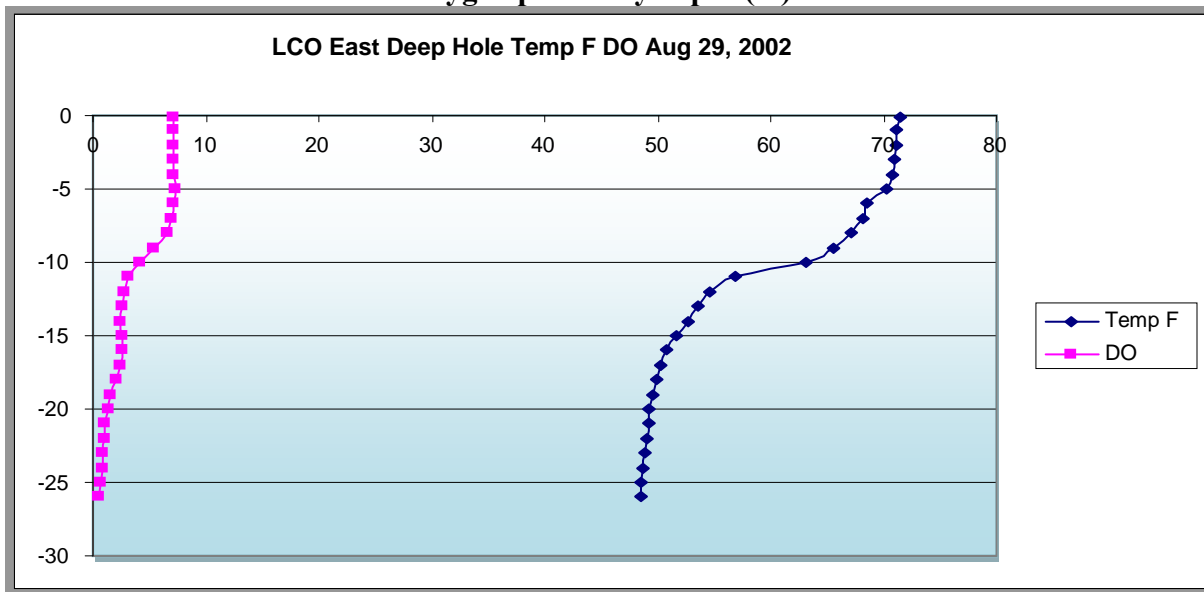


Figure 18. LCO east bay, representative late summer temperature and dissolved oxygen profile by depth (m).



New WDNR Phosphorus Rules: Stratified Lake Definition

Under the new WDNR rules (NR 102.06(g), LCO would be considered a stratified two-story lake with a stratified coefficient (e.g. $\text{Maximum Depth (m)} - 0.1/(\text{Log10 Lake Areas(ha)})$) or $((92 \text{ ft} \cdot .305) - 0.1) \cdot (\text{Log10 } 5039 \text{ acres} \cdot 0.405) = 8.4$. This value exceeds the rule value of 3.8 and hence is considered a stratified two story lake (Figure 18).

Lac Courte Oreilles Data

Growing Season Average Total Phosphorus, Chlorophyll-a and Secchi Transparency

Lake monitoring stations were established at five LCO sites (e.g. northeast, east, central, west and Musky Bays) by the LCOCD. Other sites have been monitored over time and include Stuckey, Chicago, and Grindstone Bays but that data is not included in this assessment. Laboratory analyses were contracted by the LCOCD following U.S. Environmental Protection Agency (EPA) approved methods (via the EPA approval of the LCOCD monitoring plan). Surface water lake samples were analyzed for total phosphorus and chlorophyll-a. Temperature and dissolved oxygen profiles and Secchi transparency measurements were obtained. In recent years, there were generally 2 to 9 samples per summer per lake bay and hence, trend analyses were not conducted. Data per bay was pooled and averaged for the 1996 and 2004-2008 timeframes (Figures 19 and 20).

Routine WDNR Fisheries measurement of total phosphorus data from LCO's east bay (deep site) measured from 1987 to 1998 are plotted in Figure 21, where an increasing pattern is evident. Over this time period, concentrations have nearly doubled from ~6-10 ppb to ~10-17 ppb. Recent data indicates that the east bay has remained about 9-12 ppb.

Increases in eutrophication have been noted by LCO residents. The majority (59%) of respondents to the LCO Economic Survey stated that the water quality was worse today compared to the date of purchase (average length of ownership was about 32 years). Some write-in comments included: less clarity, more aquatic plants, no frogs, more algae, wildlife

all but gone, more weeds, no clams, swimmer's itch, slime, and water not as clear. 3% of respondents believed the water quality had improved in their LCO section. Water quality degradation was perceived in all LCO sections. Economic Survey respondents overwhelmingly participate in primary contact water-related recreational activities (boating, swimming, fishing, canoeing/kayaking, and sailing).

Figure 19. Average summer total phosphorus by LCO Bay.

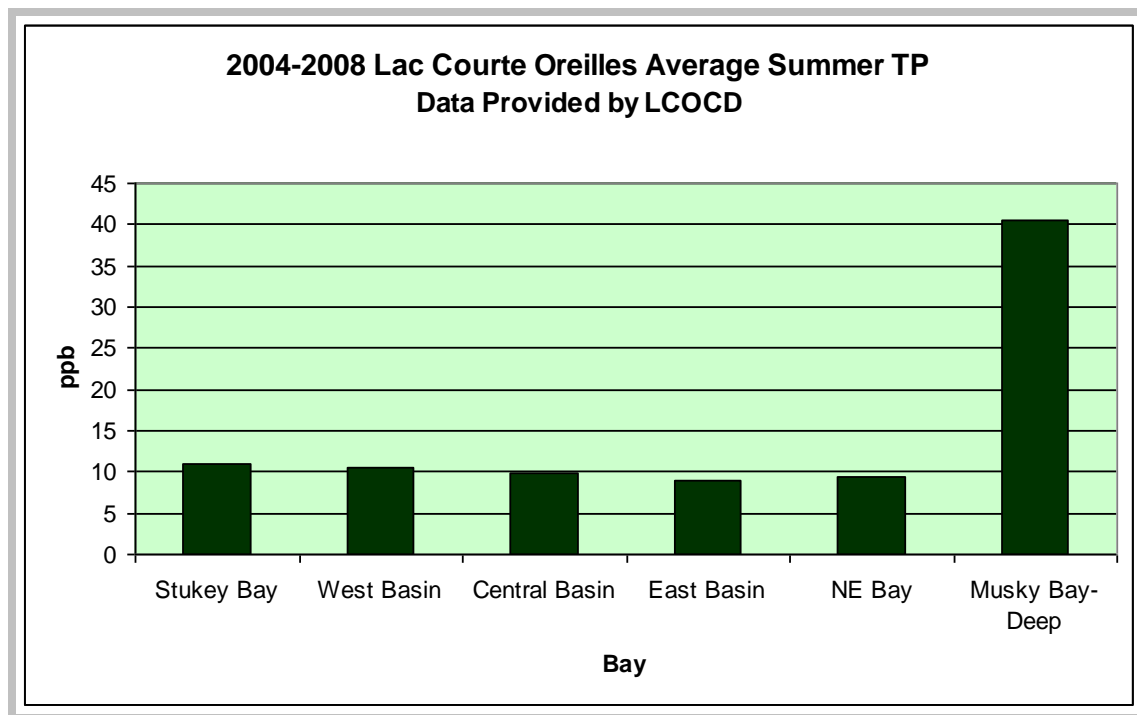


Figure 20. Average summer chlorophyll-a by LCO Bay (2004-2008).

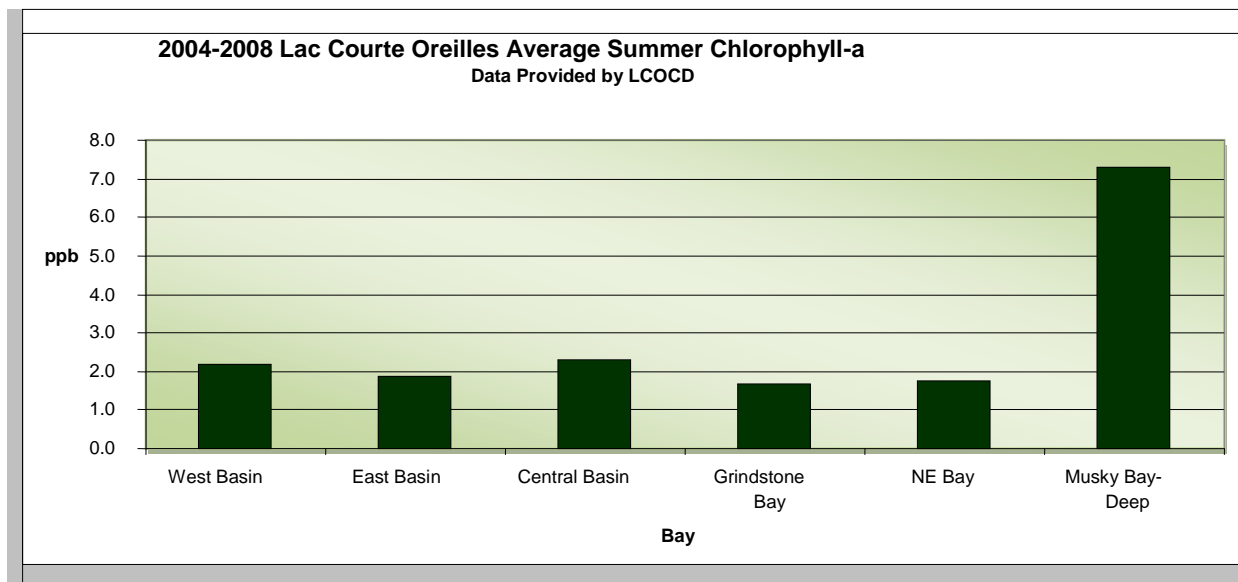


Figure 21. Historical WDNR TP Data for East Bay Deep Site (WDNR Site 583046) (1987-1998).

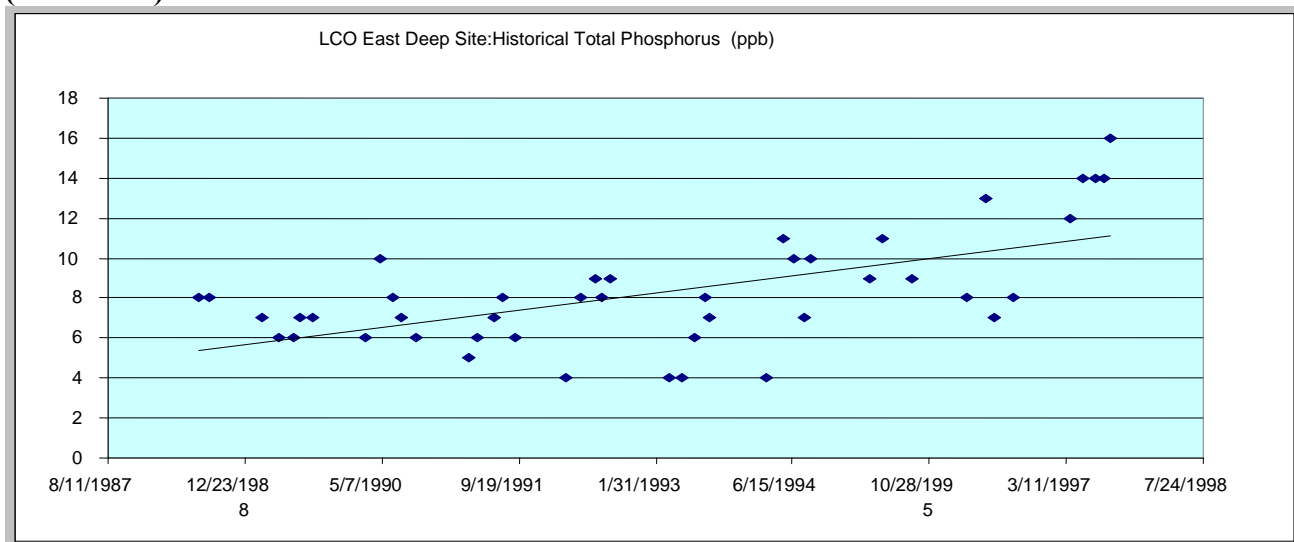


Table 12. 2004-2008 Summer Averages by LCO Bay (1996-2008 Data Provided by LCOCD).

LCO Bay	TP 2004- 2008	Chl-a 2004- 2008	Secchi 2004- 2008	Secchi 2009	Secchi 2010	Secchi 1996
Musky Bay- Deep	41.0	7.3	7.2	5.7	6.7	9.9
West Basin	10.6	2.2	15.6	15.9	16.2	13.4
Central Basin	9.8	2.3	16.9	18.3	16.8	14.2
East Basin	9.1	1.9	18.4	18.9	18.0	17.3
NE Bay	9.5	1.8	16.0	16.8	14.2	12.9
Little LCO	12	2.1	14.4	-	-	-

It should be noted that all of the LCO bays had relatively similar total phosphorus concentrations up until the 1940's when cottages and cranberry farming increased concentrations into Musky Bay (Fitzpatrick et al, 2003). Today, all bays but Musky Bay have similar P concentrations and this report makes that distinction repeatedly. As such, future goal setting should consider all of the lake as one interconnected flowage rather than different lakes embedded in separate watershed drainages. There should be one lake-wide P management goal.

LCO bay average summer total phosphorus and chlorophyll-a for 2004-2008 transition from the highest system values noted in Musky Bay and decline substantially in the west bay to the central and east bays (Table 12). For comparison purposes, except for Musky Bay, average summer total phosphorus values are comparable to the 10th percentile Northern Lakes and

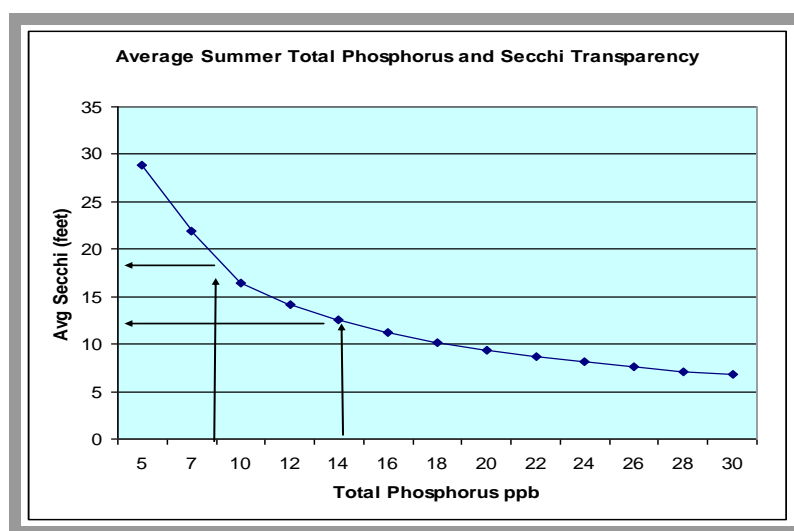
Forest ecoregion levels monitored in lake mixing types (Table 13). Musky Bay total phosphorus values are closer to the 80th percentile values for polymictic lakes. Hence, except for Musky Bay, LCO lake conditions represent excellent water quality from an ecoregion perspective. Severe infestations of Curly leaf pondweed has been associated with increased P loss as the plants die in late June, decompose and release P (0.25 + pound P/acre per year noted in Half Moon Lake (James, Barko & Sorge, (2003)).

Table 13. Average Summer Total Phosphorus Concentrations by mixing type (from Heiskary and Wilson, 1995).

Northern Lakes and Forests			
Mixing Status:	D	I	P
Percentile value for [TP]	ppb		
90 %	37	53	57
75 %	29	35	39
50 %	20	26	29
25 %	13	19	19
10 %	9	13	12
# of obs.	257	87	199

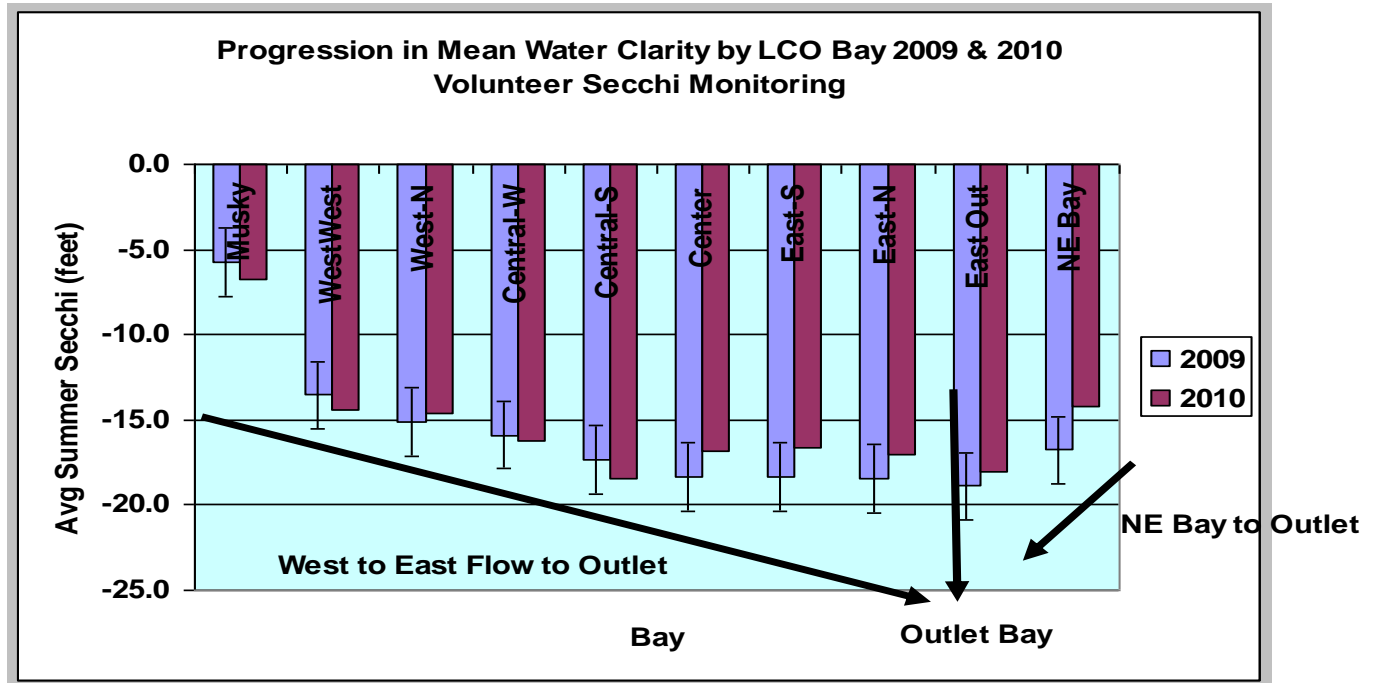
At lower total phosphorus values noted in Figure 22, transparency values will be responsive to subtle changes. Increasing phosphorus values from 9 ppb to 15 ppb can be expected to reduce transparencies from about 18 feet to ~12 feet. Average summer Secchi values are fairly consistent for 2004-2008, 2009 and 2010. These summers were generally representative of low flow conditions in contrast to the high flow conditions of the Barr study of 1996 (Barr, 1998).

Figure 22. Average summer transparency in feet as a function of total phosphorus



The progression of average summer Secchi values per bay are plotted in Figure 23, ranging from the lowest system values noted in Musky Bay to the highest readings noted in the east bay. Similar patterns were noted in both 2009 (N=9) and 2010 (N=5).

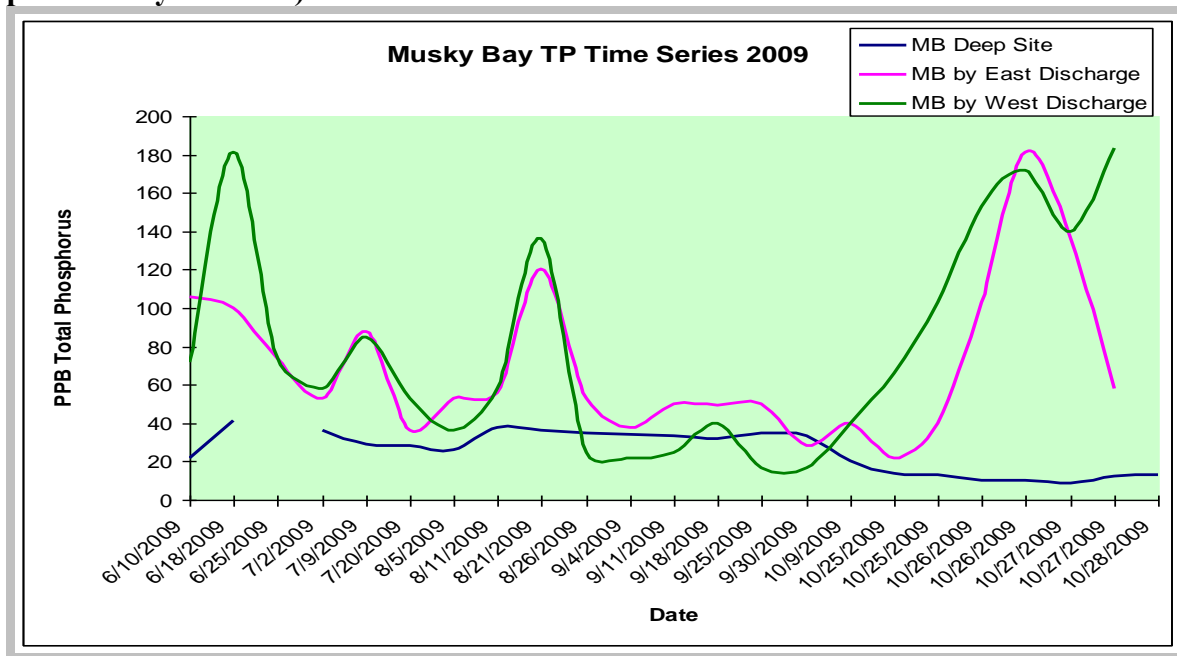
Figure 23. Average summer Secchi Transparency by LCO Bay for 2009 and 2010.



Musky Bay

The water quality of Musky Bay has been documented in other documents (LCOCD (2004, 2004b), Tyrolt (2003, 2004, 2009), Wilson (2007) and Wilson and Tyrolt (2009)). This bay has received the discharges from two cranberry dischargees (Musky Bay East and West) along with general runoff. The LCOCD has monitored the discharge total phosphorus concentrations of the East and West Musky Bay discharge flow-paths along with the main Musky Bay concentrations over the past few years with 2009 concentrations depicted in Figure 24. East and West Musky Bay cranberry discharge total phosphorus concentrations varied from ~20 to 180 ppb while the deep Musky Bay concentrations varied from ~10 – 40 ppb in 2009. Noted by samplers at the time were distinct flows out of Musky Bay into LCO west bay by the LCOCD (LCOCD, 2009). This data suggests that the noted turbid cranberry discharge flows in June, August (storm runoff) and October, 2009 were flowing through Musky Bay and into LCO west bay perhaps due to gradients caused by temperature, lack of flow impeding macrophytes (after Curly leaf pondweed treatments) or other mechanisms as evidenced by the time series of total phosphorus concentrations noted in Figure 24. Seasonal die-back of Curly leaf pondweed can also cause P enrichment as plants decompose (~0.25 pounds+ P/acre/year noted in Half Moon Lake). Hence, the quality of discharges into Musky Bay can directly affect quality of the west bay.

Figure 24. 2009 Musky Bay Time Series Total Phosphorus Concentrations (data provided by LCOCD).



Variable Climate

Future management actions should consider the effects of variable climate upon lake dynamics and the more intensive agricultural and urban land uses. Variable climate patterns that have been noted include:

- Wisconsin is becoming "less cold", with the greatest warming during winter-spring and nighttime temperatures increasing more than daytime temperatures. The LCO watershed was an 'epicenter' of summer and winter warming patterns noted from 1950-2006 with a peak warming of 2-2.5°F noted across northwest Wisconsin (WICCI, 2010).
- Long-term (1970-2009) pattern of decreasing annual mean flows for Chippewa River at Winter with a decrease runoff of about 3+ inches runoff over 39 years.
- Dry periods have cumulative impacts reducing lake levels and shallow groundwater levels. Seepage lakes in the LCO watershed, as noted for Sparkling Lake, WI by Lenters (2008), may exhibit large lake level changes.
- Increased climate variability including dry/wet cycles and increased fluctuations in upland wetland and lake levels. This may mean more drying and rewetting (changing redox) of wetlands due to variable runoff that has been associated with increased loss of phosphorus (Zak et al, 2010; Walker 1995) and increased methyl mercury formation potential (Selch et al, 2007). Increased P losses from wetlands due to variable water levels particularly during wet summer conditions with peak temperatures, is becoming an increasingly common occurrence. For example, the Pelican River Watershed District has monitored increasing P loss rates (hundreds of pounds P) during the peak summer wet periods in Rice Lake above Detroit Lakes, MN (Pelican River Watershed District, 2008). Monitoring wetland P surges were not included in this assessment, but could become significant in the future. Maintaining **vulnerable wetlands, streams and system** storage is recommended to be a primary lake management activity via protective buffers, acquisition of permanent easements and ditching/drainage/pumping activities.

- Extended dry periods as observed in 2005-2009, may also lead to greater fire danger periods, hence forest management may include measures such as under canopy biomass removal (especially old storm damage) and education and strict enforcement of ‘no burning’ periods.
- Increasing number of extreme events such as tornados and intense summer thunder storms are accompanying increasing summer dew points. The WDNR is participating in a 11 Midwest State cooperative effort with the National Oceanic and Atmospheric Administration (NOAA) to update precipitation event intensity and duration data. Updated NOAA data should be distributed in early 2012. The previous reference document, TP-40, is quite outdated (data through the late ~1950’s) and hence, storm intensity and duration values are expected to change.
- Recent regional storms particularly the derechos or super cell convective/wind storms cause massive forest damage or blow-downs as seen in northern Minnesota, increasing numbers of tornados, and large convective storm systems bringing prolonged periods of heavy rainfall. These intense storms cause damage to forests, increased erosion and runoff causing shock loadings of sediments, organic materials and nutrients to area streams and lakes. This would emphasize the importance of increased urban stormwater control measures, increasing emphasis on buffer strips around lakes and stream corridors, maintaining important upland storage within the flow networks and to avoid channelization (ditching) of wetlands and shallow lake systems.
- Longer growing seasons.
- Longer ice-free time periods. For Lake Mendota, ice cover has shortened from about 4 months to about 3 months per winter season over the 150-year period.
- More winter thaws.
- Increased evaporation of about 8 inches per year is projected over the next several decades (Stefan, Fang and Hondzo (1998). This effect may be partially offset by increased precipitation (WICCI, 2010), however, larger lake and wetland water level fluctuations may become more common. Water level management will become a more important issue as it relates to navigation between the lakes, internal lake dynamics and groundwater levels.
- Potential upland lake enrichment of Grindstone, Sand and Whitefish Lakes from shock loads, and increased internal recycling of phosphorus.

Predictive Modeling

Standard assessment predictive models are typically used for quantifying the effects of nutrient and water budgets on in-lake response variables such as total phosphorus, chlorophyll-a and Secchi transparency. These models are used to relate the flow of water and nutrients from a lake’s watershed to observed conditions in the lake. Alternatively, they may be used for estimating changes in the quality of the lake as a result of altering nutrient inputs to the lake (e.g. changing land uses or stream quality). To analyze the lake water quality of the LCO system, the US Army Corps of Engineers’ model BATHTUB (Walker, 1996) was employed. BATHTUB is a series of empirical eutrophication models that perform water and nutrient balance calculations and estimates water quality related conditions (e.g. total phosphorus, chlorophyll-a, transparency and numerous diagnostic measures). Stream gauging and sampling has not been accomplished for the LCO system. Hence, regional runoff values were determined from near-by gauging stations coupled with area monitored mean total phosphorus concentrations, which in general, are quite low and typical of the

ecoregion. As a result, the runoff modeling uncertainty is relatively high. However, in-lake responses have been extensively monitored from 1996 to 2009 and have a much greater degree of certainty. The modeling includes assumptions regarding budget components that are not directly measured (e.g., direct runoff from shoreline areas, groundwater, unmonitored tributaries, shoreline septic tanks, atmospheric loads).

Because of the relatively high ratio of watershed area to lake surface area, atmospheric fluxes are relatively significant (~30% for 2005-2009) components of the water (precipitation, evaporation) and phosphorus (deposition) budgets. Because they are difficult to measure directly, estimates of precipitation, evaporation, groundwater inflows and outflows, inputs from shoreline septic tank systems, and atmospheric phosphorus deposition introduce uncertainty into the overall water and phosphorus budgets that would be refined with a more intensive inlet and outlet monitoring. The lack of groundwater estimates or measured inflows and outflows precluded including in the modeling. As such, there are areas of uncertainty in the estimated water and phosphorus budgets that can be improved with future studies.

The water and phosphorus budgets were estimated for (1) the relatively dry period of 2005-2009 and (2) the wet year 1996 and related to measured in-lake responses. There was insufficient lake data for use of the model for other years. Future lake water quality ranges were estimated by management scenario. The LCO Economic Survey (Wilson, 2010) estimated the number of permanent, seasonal and visitors at about 84,000 days which translates into about 229 capitas. Based on Sawyer County septic tank compliance, a loss of 22.5 kg/year was estimated ($= 229 \text{ capitas} \times 0.5 \text{ kg P/capita} \times (1 - \text{soil retention of } 80\%)$).

Available historical data from stream sampling sites (Table 14) were incorporated along with average summer lake data for Whitefish and Grindstone Lakes used for defining lake outlet average stream phosphorus concentrations. This data was also compared to MINLEAP and WILMS background concentrations of 10-30 ppb. The relatively few available concentrations suggests that future monitoring should focus on Osprey Creek, Ghost Creek, and cranberry discharges. Future LCO lake monitoring should include 10-12 paired Secchi, total phosphorus and chlorophyll-a growing season measures by bay to allow for more refined quantifications. Estimates of loads from the watershed are of primary importance for evaluating the potential effects of urban development and animal/row crop agricultural. Expressing loads in terms of average inflow concentrations adjusts for differences in hydrologic conditions (e.g., wet, dry, average years).

The LCO system was segmented into four lake segments; east, central, west and Musky Bays (lake map in Appendix A). The model was calibrated to account for the relatively high Secchi transparency ranges (e.g. greater than 4 meters) historically observed in the LCO system. Available information collected by previous studies (Barr, 1998), LCOCD (2004, 2005), Tyrolt (2003, 2004, 2004b, 2009), WDNR, and USGS have been summarized to define ranges of runoff volumes, evaporation, precipitation and flow-weighted mean inflow concentrations to each bay of the flow network. Model inputs are listed in Appendix D.

Table 14. Available Monitored LCO Stream Total Phosphorus Concentrations (ppb or ug P/L) for 1996.

Location	5/20/96	5/28/96	6/4/96	6/19/96	7/3/96	7/18/96	8/2/96	8/26/96	9/16/96	9/24/96	10/8/96	Avg.
INFLOW:												
I-1, Grindstone Creek		12	10	9	11			10	11	10	12	11
I-5, Ring Lake Creek		44	24	30		30		23				30
I-8, Whitefish Creek		14	27	10	14			10	9	10	10	13
I-9, Ghost Creek	45		34	60	48		50	44	42		26	44
I-11, Osprey Creek					20	25	13		11		10	16
OUTFLOW:												
Lac Courte Oreilles Outlet		13			7		8		8		10	9

As noted in the Fisheries section, the lake's littoral substrates are comprised of sand, gravel and rock except where replaced by soft organic muck in Musky and Stuckey Bays. As such, the main lake bays have sufficient organic deposits to fuel loss of oxygen in hypolimnetic layers and release phosphorus from the sediments (called internal loading). Internal loading from the deep main bays does not look to be excessive at this time. However, the more organic debris that is deposited on the sediments, the greater the phosphorus accumulations that will occur and that may be recycled into lake waters. If watershed loading of phosphorus increases, it will fuel more algae that decompose, get deposited along the lake's sediments and hence become a source of internal phosphorus. Increased organic loading coupled with relatively long water residence times (e.g. greater than 3 years) that provides very little flushing or dilution, means that the lake's phosphorus memory is going to be relatively long to external loads including shock loads from severe events. As such, the effects of shock loading may be realized over long time periods.

Future Scenarios

Modeling of future scenarios focused on three main factors:

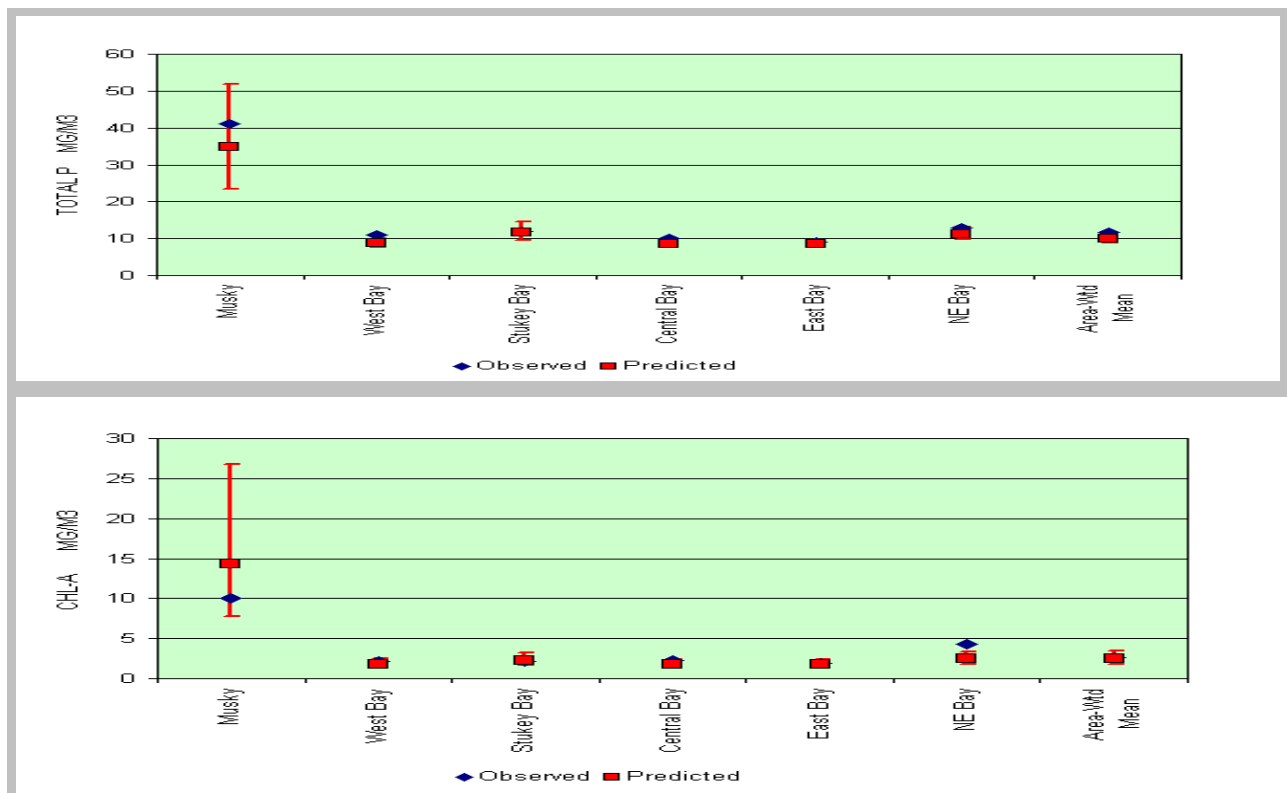
- Projected loading changes due to variable climate effects. For this purpose an increase of 30% in watershed total phosphorus loads (e.g. flow-weighted mean concentrations coupled with average flows) was used. Increased loading was attributed to these loading components:
 1. Increased P loss from wetlands due to fluctuating dry/wet cycles using a loss rate of 25 -35 mg/m²/year (Zak et al, 2010) from LCO wetlands covering about 10% of the watershed (Fitzpatrick et al, 2003) or about 690 acres (279 ha). Wetland P loss was estimated to be about 70 - 100 kg P/year.
 2. Increased annual P loads due to increased precipitation by 15% (based on annual precipitation changes projected by WICCI (2010)). Using the simple method for runoff estimation, this would correspond to increased runoff of about 15 percent using the same phosphorus concentration.

3. Increased the loads to LCO by 10% to reflect increasing occurrence of large intense storms, peak snowpack melts and other shock loading events. A worst case loading event might occur during snowpack melt with intense spring storms after forest fires.
- Increased internal loading. Effects on internal loading from the combination of longer growing season, warmer hypolimnetic temperatures, more intense storm induced mixing events, and watershed organic & P loads. For this purpose, a sediment release rate of 1.0 mg/m²/day was employed.
- A sensitivity analysis of impacts by bay resulting from a range of P increases was accomplished.

Modeling Results

Lake modeling of 2005-2009 - dry conditions was accomplished using watershed runoff and lake outlet volumes calculated as defined in this report. The model estimated average Secchi within 7% in all bays except for Musky Bay which has different macrophyte-algal interactions. 1996 wet year conditions were then estimated as using a much smaller verification dataset with predicted water quality within +/- 25% of observed values generally observed.

Figure 25. Dry year (2005-2009) average observed and predicted (a) total phosphorus by LCO bay (b.) chlorophyll-a and (c) Secchi transparency.



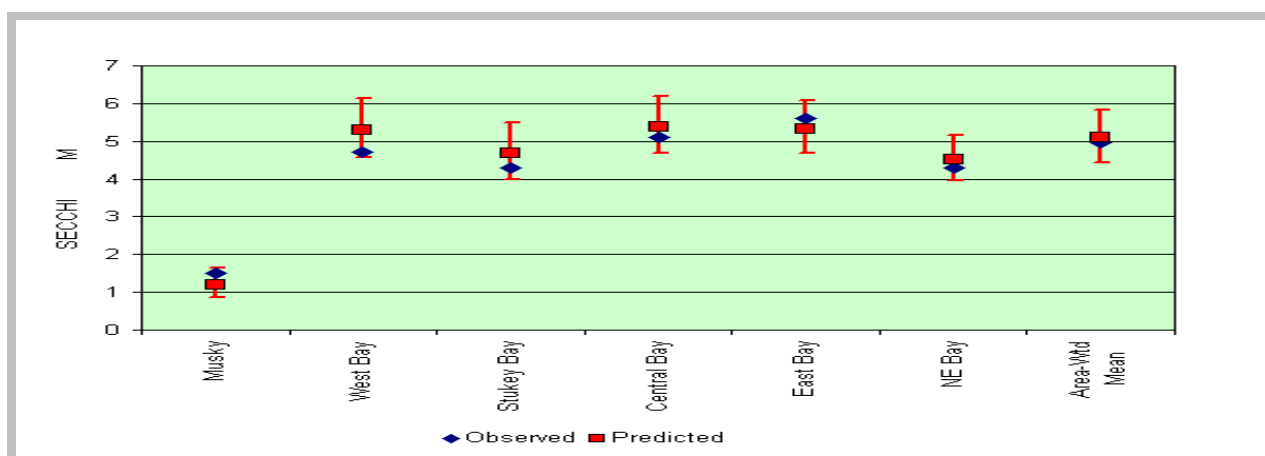


Table 15. Summary of Dry Years (2005-2009) BATHTUB Predicted vs. Observed LCO Water Quality Parameters

2005-2009 Averages Entire LCO	Predicted Average Summer				Observed Average Summer			
	Total P	Chl-a	Secchi m	Secchi ft	Total P	Chl-a	Secchi m	Secchi ft
average	10	2.6	4.9	16.1	12	2.6	5.0	16.4
Musky Bay	35	14	1.2	3.9	41	10	1.5	4.9
West Bay	9	1.9	5.1	16.7	11	2.2	4.8	15.7
Stuckey Bay	12	2.9	4.1	13.4	12	2.1	4.3	14.1
Central Bay	9	1.9	5.2	17.1	10	2.3	5.1	16.7
East Bay	9	1.9	5.2	17.1	9	1.9	5.6	18.4
NE Bay	11	2.8	4.2	13.8	13	4.3	4.3	14.1

Table 16. Summary of Wet Year (1996) BATHTUB Predicted vs. Observed LCO Water Quality (Secchi)

1996 Conditions	Predicted Average Summer				1996 Observed
1996 Wet Year	Total P	Chl-a	Secchi m	Predicted Secchi ft	Observed Secchi Ft
Entire LCO					
average	10	2.7	4.8	15.7	14.6
Musky Bay	32	13	1.3	4.3	9.9
West Bay	9	2	5.1	16.7	13.4
Stuckey Bay	15	4.1	3.5	11.5	
Central Bay	9	2	5.1	16.7	14.2
East Bay	9	2	5.1	16.7	17.3
NE Bay	12	3	4.1	13.4	12.9

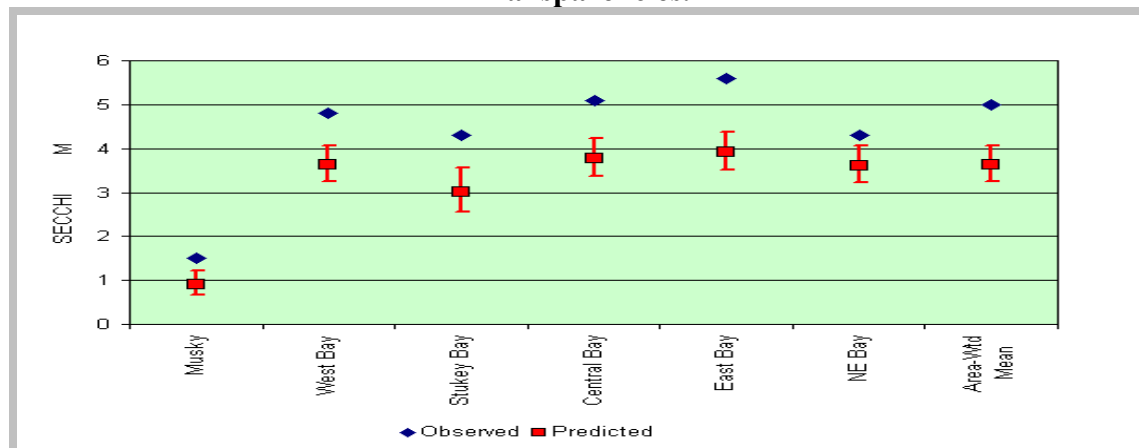
Table 17. Predictions with long-term average flows and 30% increase in stream P loading.

Average Year Flows	Predicted Average Summer				2005- 2009 Observed	% change
	Total P	Chl- a	Secchi m	Predicted Secchi ft	Secchi ft	
Entire LCO average	13	3.4	4.1	13.4	16.4	-18%
Musky Bay	33	13	1.2	3.9	4.9	-20%
West Bay	10	2.4	4.5	14.8	15.7	-6%
Stuckey Bay	14	4	3.5	11.5	14.1	-19%
Central Bay	11	2.6	4.4	14.4	16.7	-14%
East Bay	12	3	4.1	13.4	18.4	-27%
NE Bay	17	5.2	3.1	10.2	14.1	-28%

Table 18. Variable Climate Effecting Internal P Loading (1mg/m2-day over lake surface area).

	Predicted Average Summer				Observed	% change
	Total P	Chl- a	Secchi m	Secchi ft	Secchi ft	
Dry Year Internal P Entire LCO average	15	4.6	3.6	11.8	16.4	-28%
Musky Bay	50	24.7	0.9	3.0	4.9	-40%
West Bay	14	3.7	3.6	11.8	15.7	-25%
Stuckey Bay	18	5.3	3	9.8	14.1	-30%
Central Bay	13	3.5	3.8	12.5	16.7	-26%
East Bay	13	3.2	3.9	12.8	18.4	-30%
NE Bay	14	3.8	3.6	11.8	14.1	-16%

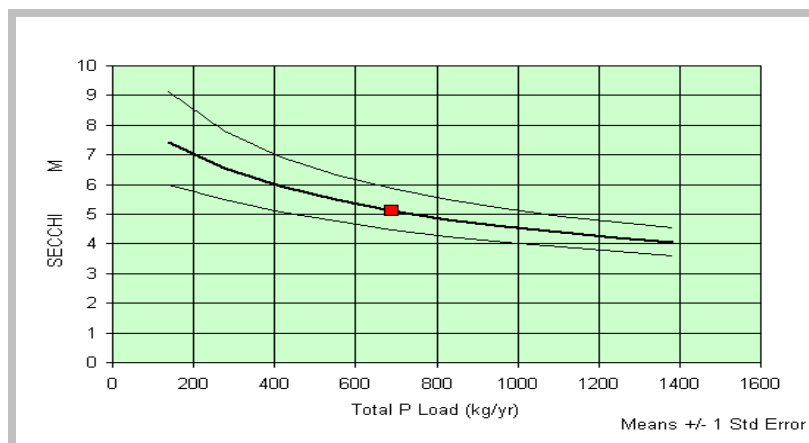
Figure 26. Variable Climate Affecting Internal Loading (1 mg/m2-day over lake surface area) and Predicted Bay Average Summer Transparencies.



Modeling Conclusions

1. The USACE model BATHTUB was employed to simulate recent water quality patterns with estimated flows and monitored stream concentrations through the LCO system.
2. The model reasonably estimated recent dry conditions (2005-2009) with predicted Secchi generally within 7% of observed values. Wet year (1996) with ~9th percentile high flow was also modeled and predicted in-lake responses were reasonable, given available data.
3. Future conditions. Modeling indicates that increasing stream phosphorus flow-weighted mean concentrations by 30% would result in observable declines in average summer Secchi transparency to long-term residents on the order of 20% to 30%. Higher declines in Secchi transparency were estimated for deep bays due to the sensitivity of the phosphorus:Secchi.
4. Increased income of phosphorus/organic materials was predicted to increase in-lake productivity (e.g. chlorophyll-a). At some point, these external increases lead to increases of internal phosphorus recycled from the lake sediments. It is anticipated that lake mixis coupled with warmer temperatures and longer summer stratification periods will tend to increase internal loading sources (both oxic and anoxic release rates). For illustration, a value of 1 mg/m²-day internal loading rate was predicted to decrease LCO area-weighted average summer Secchi values bay about 28% .
5. Long-term WDNR monitored phosphorus data for the East bay generally confirms the range of water quality estimated by the modeling. Historical data suggests that the east bay's total phosphorus concentrations increased from 6 ppb to over 15 ppb during the 1980's and 1990's.
6. **Sensitivity Analysis:** Based on sensitivity analyses of the 2005-2009 model, LCO bays will be extremely sensitive to nutrient inputs such that relatively small increases (e.g range of 50 to 300 kg P/Year (or about 110 to 660 pounds)) by bay, will likely cause observable losses in average summer transparency (e.g. 0.5 to 2 meters or 1.5 to 7 feet loss in average transparency ranges) in the west (Figure 25), central and east LCO bays. From a lakeshore owner's perspective, about 50% of LCO Economic Survey respondents indicated that this range of transparency losses would negatively affect their continuing ownership of LCO related properties.

Figure 27. BATHTUB Load Response for West Basin, Mean Secchi as function of P load.



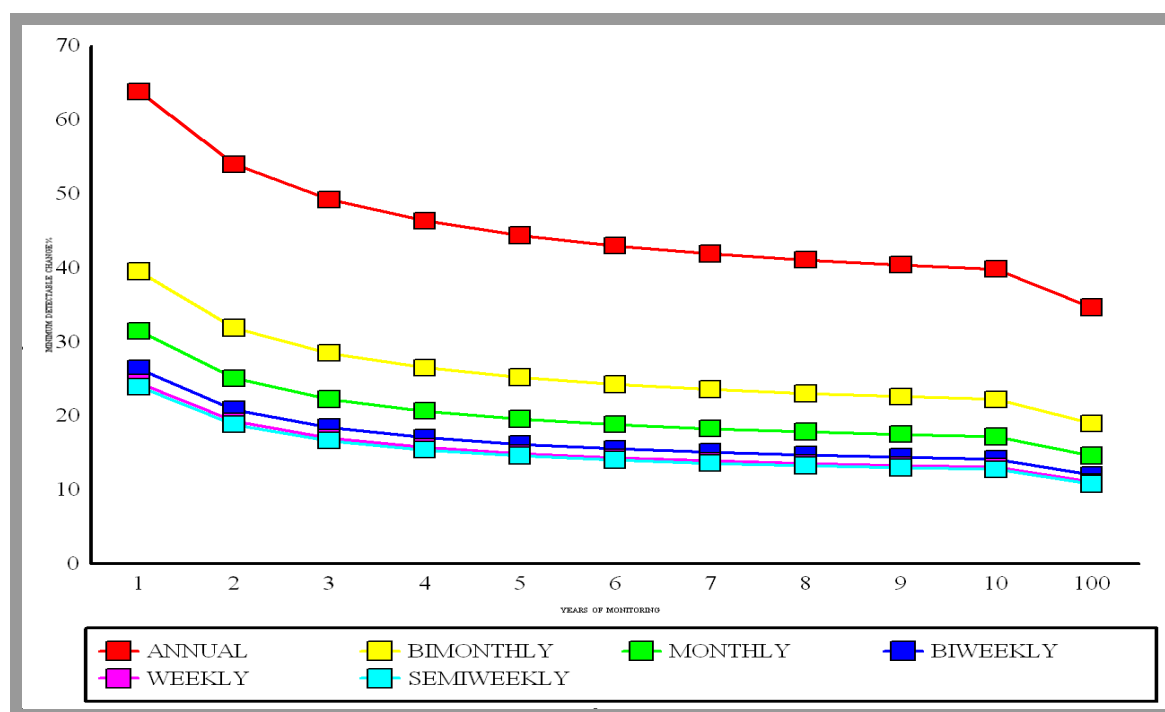
Cumulative impacts of variable climate may be expected to increase P loading to LCO. Subtle increases in forest runoff may be expected with variable climate and infestations, fires

and shock loadings resulting from intense storms. Values for these changes were estimated to range up to 30%. Coupled with longer growing seasons and warmer temperatures, this increase can be expected to influence lake internal P loading. Very small changes in internal loading rates will tend to reduce transparencies with modeling indicating a potential for loss of 4-6 foot of average summer transparencies.

Trend Detection.

Future water quality trend detection should be primarily based on total phosphorus and Secchi transparency measures. Increasing the monitoring effort to semi-weekly or weekly measurements intervals over 3-5 years allows detection of 15% to 25% changes in summer average Secchi in each of the LCO bays. Statistics for total phosphorus were calculated using LRSD software (Walker, 1990) with an assumed 100 day summer monitoring period and standard total phosphorus statistics. If monitoring frequency is reduced to once a month, the minimum statistically detectable change increases to about 40% to 50% (Figure 24). Chlorophyll-a measures can exhibit much greater variability, and hence, it is recommended to base future trend detection on Secchi and total phosphorus measurements.

Figure 28. Detecting minimum average summer total phosphorus changes as a function of number of years and monitoring frequency as estimated by LRSD (Walker, 1990).



Conclusions

1. LCO is a designated Outstanding Resource Value waterbody located in Sawyer County, classified as an oligotrophic lake (Garrison and Fitzgerald, 2005). It is Wisconsin's eighth largest natural lake (Pratt, 1977) covering 5,039 acres that represents about 9% of Sawyer County's lake acreage.
2. LCO with its four main bays and Little Lac Courte Oreilles, are regionally exceptional lakes in terms of their size, water quality, including LCO's historical two story fishery and general habitat. This is due in large part to the number of upstream wetlands and lakes that act as sediment and nutrient traps.
3. Most water flows into and out of LCO occur through the east bay - except for bay-to-bay wind mixing. With much less water runoff reaching other bays, the central and west bays have much longer water residence times (e.g. estimated 5 and >>20 years, respectively versus the east bay's estimated residence time of ~ 2 years during dry year of 2009).
4. Variable climate has been noted over the past two decades including swings from wet years (1996 and 2002) to drought conditions (2005-2009), intense storms, reduced stream flows and longer growing seasons. Over the past 40 years, there has been a declining regional runoff pattern (about 18% less) for the Chippewa River at Winter, WI. This has resulted in greater water level fluctuations of wetlands, streams and lakes.
5. Key challenges include maintaining forests & waters (that make up about 2/3's of the watershed) in an increasingly variable climate with droughts, fires, wet periods, intense storms (damage, erosion and shock loads to lakes and streams) and longer growing seasons and ice-free periods.
 - a. LCO has certain characteristics of depth, fetch and orientation that when coupled with longer growing seasons and increased organic loading may result in increased internal loading potential. Minor increases in loading can be rapidly translated into reduced summer transparencies.
 - b. Exotic infestations – some exacerbated by variable climate- will have significant effects on lake and forest resources. Curly leaf pondweed infestations die-back each early spring and provide enrichment of the lake sediments with organic material and P loss that will stimulate algal growth.
 - c. Variable climate factors appear to have more lake-degrading potential than improvement potential by this assessment. The longer growing seasons and warmer temperatures will result in higher lake temperatures, extreme storm mixing events and dry/wet cycles can be translated into greater watershed P losses. These forces, if not offset by protective actions, will likely result in increased lake P concentrations.
6. The cumulative effects of the pounds of phosphorus reaching LCO is significant as each part per billion increase in LCO average summer total phosphorus can result in a loss of about one foot of average summer water clarity, particularly in the east and central LCO bays.
7. Most LCO Economic Survey respondents (52%) chose their property location because of the water-related recreational opportunities with 57% desiring to maintain long-term family ownership of their property. Additionally, 11% of survey respondents indicated that they were planning on permanent LCO residency at some point in the future. These latter two findings have positive implications for providing long-term ownership stability to the region.
8. The long-term WDNR phosphorus data for the east bay shows a substantial increase that occurred from the late 1980's through the late 1990's. Reinforcing this pattern, 59% of

LCO Economic Survey respondents stated the water quality was worse today (than when purchased with an average resident tenure of 32 years) as evidenced by their observations including: — less clarity, more aquatic plants, no frogs, more algae, wildlife all but gone, more weeds, no clams, swimmer's itch, slime, and water not as clear.”

9. The USACE model BATHTUB was employed to simulate recent water quality patterns with estimated flows and monitored stream concentrations through the LCO system.
 - a. The model reasonably estimated recent dry conditions (2005-2009) with predicted Secchi generally within 7% of observed values. Wet year (1996) with ~9th percentile high flow was also modeled and predicted in-lake responses were reasonable, given available data.
 - b. Future conditions. Modeling indicates that increasing stream phosphorus flow-weighted mean concentrations by 30% would result in observable declines in average summer Secchi transparency to long-term residents on the order of 20% to 30%. Higher declines in Secchi transparency were estimated for deep bays due to the sensitivity of the phosphorus:Secchi relationship. This range of potential future changes in water quality are relevant as related to lake shore owners maintaining property ownership.
 - i. From the LCO Economic Survey, the future water quality appears to strongly influence future intent to maintain property ownership. Progressively larger losses in summer water clarity resulted in greater percentages of survey respondents not desiring to continue ownership. Loss of 2 – 3 feet average summer clarity resulted in 20% “not staying”, 4 – 6 feet loss resulted in 48% of responses “not staying” and loss of 7-10 feet clarity resulted in 59% “not staying”. These findings are noteworthy considering the widespread desire to maintain long-term family ownership of LCO properties noted in the same survey.
10. From the LCO Economic Survey, LCO is a popular and regionally recognized Hayward Area destination receiving an estimated 84,000 visitor days per year from full-time LCO residents + seasonal LCO residents (second home property owners) + their LCO guests - estimated from mail-in surveys sent to 650 LCO residents.
 - a. LCO residents and their guests purchase a wide variety of goods and services with estimated LCO resident annual expenditures, varying from about \$2 million dollars for trade services (plumbing, electricians, carpenters etc), \$1.5 million for building supplies, \$1.3 million for groceries and utilities, \$948 thousand dollars for marine/snowmobile, \$801 thousand for dining out, and \$703 thousand for automotive. Survey responses were summed by category from the 219 respondents and then extrapolated to 650 LCO residents.
 - b. In total, estimated LCO resident total 2009 expenditures were ~\$9.8 million. Using a range of multipliers, the total effects of these expenditures in the LCO region was approximated to be about \$ 10.8 million to \$14.8 million annually.
 - c. These values represent about 9% of total Sawyer County travel and tourism revenue noted in 2008. Statewide travel and tourism, referred to as one of the three pillars of Wisconsin industry along with agriculture and manufacturing, was estimated by the Wisconsin Department of Tourism to be about \$12 billion in 2009 and responsible for about 300,000 jobs (Davidson-Peterson Associates, 2010).

Recommendations

1. The ‘Northwood Charm’ is a significant, in a business sense, ‘product’, of the region. Competing for and sustaining future travel and tourism will be dependent upon maintaining the quality of the product, otherwise discretionary travel dollars will be spent elsewhere.
2. LCO has been a two story fishery and should be managed to maintain average summer total phosphorus at present levels or lower. This will mean antidegradation or protection efforts will be needed to maintain 9 -12 ppb total phosphorus.
3. An interim or short-term (e.g. 5 year) goal for Musky Bay of 20 ppb should be established. The long-term recommended total phosphorus goal for Musky Bay is 10 ug P/L. Adaptive management of the watershed coupled with monitoring should be pursued in this regard.
4. Information Gaps and LCO Monitoring Recommendations. The hydrology of the LCO system was estimated from near-by gauging stations over the range of low to high flow years. The lake outlet should be gauged to better define water flushing rates and likely groundwater contributions.
 - a. Initiate continuous flow gauging along Osprey Creek and the LCO outlet where best flows can be obtained with consideration of backwatering and tied into lake level gauge. This will require a continuous computerized gauging station with development of staff-discharge relationships for the flowage.
5. Lake levels should be monitored using volunteer efforts along with tracking of ice-on, ice-out, and monthly lake level readings June through October.
6. Measure temperature and dissolved oxygen profiles: spring after iceout, early summer, end of June, mid July, mid-August and mid-September in all four LCO Bays.
7. Groundwater elevation data was not reviewed in this report and representative long-term well water levels should be monitored. The magnitude of groundwater contribution to LCO should be better quantified with outlet monitoring and tracking of seasonal flow patterns including the lake levels of seepage lakes such as Durphee Lake.
8. Hence, antidegradation should be a primary focus of future management efforts with a high priority of protecting forest and wetland areas with low runoff P characteristics. Vulnerable wetlands, forests and streams should be more carefully identified along with appropriate BMPs, protective easements and enforcement.
 - a. Some important considerations for improving and protecting the water quality of the lake include implementation of BMP’s in the shoreland area and with a particular emphasis on the direct drainage areas, particularly in the Osprey Creek area. Proper maintenance of buffers areas between lawns and the lakeshore, minimizing use of fertilizers, and minimizing the introduction of new significant sources of P-loading (e.g., stormwater from near-shore development activities in the watershed), will serve to minimize loading to the lake. Future development should minimize compaction and disturbance of soils, emphasize on-site treatment of runoff via low impact development techniques and require shoreland buffers. Continued vigilance for proper functioning of on-site septic tanks in shoreland areas is needed.
9. Work with owners to eliminate cranberry discharges to the lake.
10. Refined Trend Detection. 10-12 paired total phosphorus, chlorophyll-a and Secchi transparency readings with recreation suitability and physical appearance evaluations per LCO bay per growing season. These readings should be taken over the next 3 or 4

years to provide statistical foundation data for statistically detecting future 15% to 25% shifts in Secchi and total phosphorus.

- a. Upstream lake groups are also encouraged to partner in monitoring of Sand, Whitefish, Grindstone and Osprey Lakes. This should include water quality and lake level monitoring of the seepage lakes (Durphee, Windingo and Ring).

11. Continued education. Another significant effort should be made to increase public awareness on the condition of these lakes. The LCO Economic Assessment defines the economic impact of the 'Northwood' product. This is well stated by Krysel, et al (2003) –The evidence shows that management of the quality of lakes is important to maintaining the natural and economic assets of this region.”

References

Barr Engineering, Company. April, 1998. Lac Courte Oreilles Management Plan: Phase I Water Quality Study of Lac Courte Oreilles; Phase II: Hydrologic and Phosphorus Budgets. Prepared for the Lac Courte Oreilles Conservation Department.

Carlson, R.E. 1977. A trophic state index for lakes. *Limnol. Oceanog.* 22:361-369
<http://dipin.kent.edu/tsi.htm>

Engel, Bernard A. 2010. Watershed Delineation Program. Department of Agricultural & Biological Engineering, Purdue University. West Lafayette, IN, 47907-2093
<https://engineering.purdue.edu/>

Fitzpatrick, Faith, Paul J. Garrison, Sharon A. Fitzgerald, and John F. Elder. 2003. Nutrient, Trace-Element, and Ecological History of Musky Bay, Lac Courte Oreilles, Wisconsin, as inferred from Sediment Cores. US Geological Survey Water Resources Investigations Report 02-4225. Middleton, WI. 141pp.

Frelich, Lee, C.M.Hale, S. Scheu, A.R. Holdsworth, L. Heneghan, P.J. Bohlen and P.B. Reich. 2006. Earthworm invasion into previously earthworm-free temperate and boreal forests. *Biol. Invasions*: 8:1235-1245.

Garrison, Paul J. and Sharon A. Fitzgerald. 2005. The role of shoreland development and commercial cranberry farming in a lake in Wisconsin, USA. *J. Paleolimnol* (2005) 33: 169-188.

Harmony Environmental. 2007. Macrophyte Survey of Musky Bay, Lac Courte Oreilles.

Heiskary, S. and C. B. Wilson. 1989. The regional nature of lake water quality across Minnesota: an analysis for improving resource management. *J. Minn. Acad. Sci.* 55(1):71-77.

Ibid. 2005. Minnesota lake water quality assessment report - developing nutrient criteria: third edition. MPCA, St. Paul MN. <http://www.pca.state.mn.us/publications/reports/lwq-a-nutrientcriteria.pdf>

Heiskary, S.A., C.B. Wilson, and D.P. Larsen. 1987. Analysis of regional patterns in lake water quality: Using ecoregion for lake management in Minnesota. *Lake and Res. Manage.* 3:337-344.

Heiskary, S.A. and C. B. Wilson. 2008. Minnesota's Approach to Lake Nutrient Criteria Development. *Lake and Res. Mgmt.* Vol. 24:282-297.

Iowa Climate Change Impacts Council, 2011. Climate Change Impacts on Iowa 2010. Report to the Governor and the Iowa General Assembly. <http://www.iowadnr.gov/iccac/index.html>

James, W., J. Barko, H. Eakin and P. Sorge. 2002. Phosphorus budget and management strategies for an urban Wisconsin lake. *Lake and Res. Mgmt.* 18(2): 149-163.

LCOCD, 2004. Report to Alf Sivertson dated October 14, 2004 11pp.

LCOCD, 2005. Report to Alf Sivertson dated January 21, 2005. 43pp.

Lenters, J. D., 2008: Low lake levels in northern Wisconsin. LakeLine (Quarterly publication of the North American Lake Management Society). v. 28, pp. 17-19.

Liebl, David S. 2010. Adapting to Climate Change in Wisconsin, Strategies for Conservation Professionals. Presented at Wisconsin Land and Water Conservation Association. Wisconsin Initiative on Climate Change Impacts. University of Wisconsin Cooperative Extension.

Moss, Brian, Jane Madgwick and Geoffrey Phillips. 1997. A Guide to the Restoration of Nutrient Enriched shallow lakes. Broads Authority, 18 Colegate, Norwich, Norfolk, NR3 1BQ

Panuska, J.C. and J. C. Kreider. 2003. Wisconsin Lake Modeling Suite Program Documentation and User's Manual Wisconsin Department of Natural Resources PUBL-WR-363-94

Pelican River Watershed District. 2008. Upper Pelican River Nutrient Management Project. <http://www.prwd.org>.

Pratt, Frank. 1977. 1976 Comprehensive Survey, Lac Courte Oreilles. WDNR Memo to L.G. Hansen.

Pratt, Frank and Dave Neuswanger. 2006. Fishery Management Plan Lac Courte Oreilles Sawyer County, Wisconsin. 18pp.

Pratt, Frank. 2010. Review of the Lac Courte Oreilles Fisheries File with Gary Pulford, December 10, 2010.

Pulford, Gary. 2009. Personal communication regarding the loss of lake level in Musky Bay and Lac Courte Oreilles over the summer of 2009 based on lake shore exposed and dock depth.

Schupp, D. 1992. An ecological classification of Minnesota lakes with associated fish communities. MDNR Investigational Report No. 417. St. Paul MN. 27 pp

http://files.dnr.state.mn.us/publications/fisheries/investigational_reports/417.pdf

Schupp, D. and C.B. Wilson. 1993. Developing lake goals for water quality and fisheries. LakeLine. December, 1993 pp.8-21.

Selch, T.M., C.W. Hoagstrom, E.J. Weimer, J.P. Duehr and S. R. Chipps. 2007. Influence of fluctuation in water level of Mercury in adult walleyes. Bull. Environ. Cont. Toxicol (79:36-40.

Stefan, Heinz G., X. Fand, and M. Hondzo. 1998. Simulated climate change effects on year-round water temperatures in temperate zone lakes. Climatic Change 40: 547-576.

Shieffer, Steven. 2008. Survey of *Potamogeton crispus* (Curly leaf pondweed) Musky Bay-Lac Courte Oreilles. 7 pp.

Tyrolt, Daniel. 2003. Memo to Alf Sivertson dated March 28, 2003. 80 pp.

- Tyrolt, Daniel. 2004. Memo to Alf Sivertson dated February 23, 2004 32pp.
- Tyrolt, Daniel. 2004b. Memo to Paul Garrison dated July 13, 2004 117pp of phytoplankton enumeration for 2004 and 2005 by University of Duluth, NRRI
- Tyrolt, Daniel. 2009. Various spreadsheet summaries of 1996-2008 watershed lake and stream data provided to CBWilson.
- Walker, W. W. 1995. Design basis for Everglades stormwater treatment areas. *Water Resources Bulletin* 31(4):671-685.
- Walker, W.W. 1996. Simplified procedures for eutrophication assessment and prediction: user manual. Instruction Report W-96-2. U.S. Army, Technical Report E-81-9. USAE Waterways Experiment Station, Environmental Laboratory. Vicksburg, Mississippi.
- Wilson, Bruce and William Walker, 1989. Development of Lake Assessment Methods Based on the Aquatic Ecoregion Concept. *Lake and Res. Manage.* 5(2): 11-22.
- Wilson, Bruce. 2007. Presentation to the Legislative-Citizens Commission on Minnesota Resources —Tracking urban changes across Minnesota: 1990-2000.” St. Paul.
- Wilson, C. Bruce. 2007. Review of Musky Bay Water Quality Data Lac Courte Oreilles, Sawyer County, Wisconsin submitted to the Wisconsin Department of Natural Resources.
- Wilson, C. Bruce and Daniel Tyrolt. 2009. Lac Courte Oreilles, Sawyer County, Wisconsin. 2010 WisCALMS Review. Submitted to the Wisconsin Department of Natural Resources Lakes Partnership.
- Wilson, C. Bruce. 2010. Lac Courte Oreilles Economic Survey and Assessment. Prepared for the Wisconsin Department of Natural Resources under a Lake Management Grant to the Courte Oreilles Lakes Association. 24 pp.
- Wisconsin Initiative on Climate Change Impacts, 2010.
<http://www.wicci.wisc.edu/resources.php>
- Zak, Dominik, CWagner, B. Payer, J. Augustin, and . Gelbrecht. 2010. Phosphorus mobilization in rewetted fens: the effect of altered peat properties and implications for their restoration. *Ecological Applications* 20(5): 1336-1349.